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HRP RADIATION CORROSION STUDIES

IN-PILE LOOP L-4-8

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N. C. Bradley
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IN-PILE LOOP L-4-8

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Report Prepared
by
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CONTENTS

SUMMARY 1

INTRODUCTION 1

CONSTRUCTION AND PREPARATION OF LOOP 1

IN-PILE OPERATION 3

- General Operating Conditions and Procedures 3
- Results of Solution Analyses, Oxygen Consumption, and Fission Power in Loop 7
- Uranium Balance and Radiolytic-Gas Pressure 7
- Corrosion Indicated by Nickel, Oxygen, and Manganese Data 16

REMOTE DISMANTLING AND INSPECTION 16

- Dismantling 16
- Qualitative Results of Inspection and Evaluation 16
- Quantitative Results of Inspection and Evaluation 19

DISCUSSION OF RESULTS 19

- Zircaloy-2 19
- Titanium 55AX 20
- Stainless Steel 28
- Stress Specimens 30
- Correlation Between Nickel and Weight Data 30

REFERENCES 30

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HRP RADIATION-CORROSION STUDIES (IN-PILE LOOP L-4-8)

SUMMARY

A fifth in-pile loop experiment, L-4-8, was completed. The loop operated in-pile for a total of 1637 hr, during which time the LITR energy output was 4377 Mwhr. The average fission power in the loop based on cesium analyses was 622 w when the LITR was at full power (3 Mw). Based on oxygen data, the generalized corrosion rate for the first 300 hr was 4.0 mpy; the rate for the remaining 1337 hr was 0.7 mpy. The nickel data gave parallel results. The corrosion of the type 347 stainless steel, Zircaloy-2, and Ti-55AX coupons exposed in the core and in in-line holders was generally consistent with that observed in previous in-pile loop experiments. Some differences with steel were attributed to the fact that this was the first loop containing steel specimens operated with 0.04 *m* H_2SO_4 present in the uranyl sulfate charge solution (0.17 *m* UO_2SO_4, 0.03 *m* $CuSO_4$).

Stress specimens, made from the alloys Zircaloy-2, type 17-4 PH stainless steel, and Ti-C-130-AM, were exposed in core, in-line, and pressurizer locations. Microscopic examination and average weight loss gave no indication of effects attributable to the stressed condition of the specimens.

INTRODUCTION

The major portion of the fifth in-pile loop experiment, L-4-8, has been completed. Metallographic examination of exposed specimens remains to be done and comprises the uncompleted portion. The methods, equipment, and procedures employed in this experiment were similar in most respects to those reported for the previous four loop experiments, and reference is made to the previous reports for details not included here.[1-4]

CONSTRUCTION AND PREPARATION OF LOOP

A list of the specimen materials and types which were exposed in this loop is given in Table 1. Corrosion coupons in Zircaloy-2 tapered-channel holders were installed in both the in-line and core positions. The arrangement of coupons in the holders is shown in Fig. 1*a*. An identical arrangement was employed with the previous loop, EE.[4] Two rod-and-sleeve assemblies were installed in the core position, replacing the coupled specimen used in loop EE. One assembly was of type 347 stainless steel throughout, and the other was of type 309 SCb stainless steel. Both assemblies were mounted in spiders, together with stress-specimen assemblies, around the coupon holder in the core as shown in Fig. 1*b*.

As indicated in Table 1, stress specimens were placed in three locations: the core, the pressurizer, and a special in-line holder. The pressurizer assemblies were so arranged that one stressed assembly of each of the test materials was exposed to solution and one to vapor. Photographs of the pressurizer and in-line stress specimens are shown in Figs. 2 and 3, respectively. The type C-130-AM titanium and hardened type 17-4 PH stainless steel are materials of high yield strength which are under consideration as bolting material for the fuel-contacting joint between the HRT core and pressure vessel.

Prior to installation in the loop, the Zircaloy-2 specimens were stress relieved by heat treatment at 1200°F for ½ hr. The coupons were then sanded and the stress specimens sandblasted to remove the film developed during the heat treatment.

The 17-4 PH stainless steel stress specimens were annealed for ½ hr at 1900°F, oil quenched, and then heat treated for 2 hr at 1000°F and air cooled. Rockwell hardness values for all specimens were between C-38 and C-40.

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TABLE 1. CORROSION SAMPLE UNITS, LOOP L-4-8

Specimen Type and Position	Material and Number
Core holder coupons	8 Stainless steel, type 347 8 Zircaloy-2 8 Titanium 55AX
Core stress-specimen assemblies	2 Zircaloy-2 2 Titanium C-130-AM 2 Stainless steel, type-17-4 PH
Core sleeve specimens	8 Stainless steel, type 347 8 Stainless steel, type 309 SCb
In-line holder coupons	8 Stainless steel, type 347 8 Zircaloy-2 8 Titanium 55AX
Special in-line stress-specimen assemblies	1 Zircaloy-2 1 Titanium C-130-AM 1 Stainless steel, type 17-4 PH
Pressurizer stress-specimen assemblies	2 Zircaloy-2 2 Titanium C-130-AM 2 Stainless steel, type 17-4 PH 2 Stainless steel, type 347

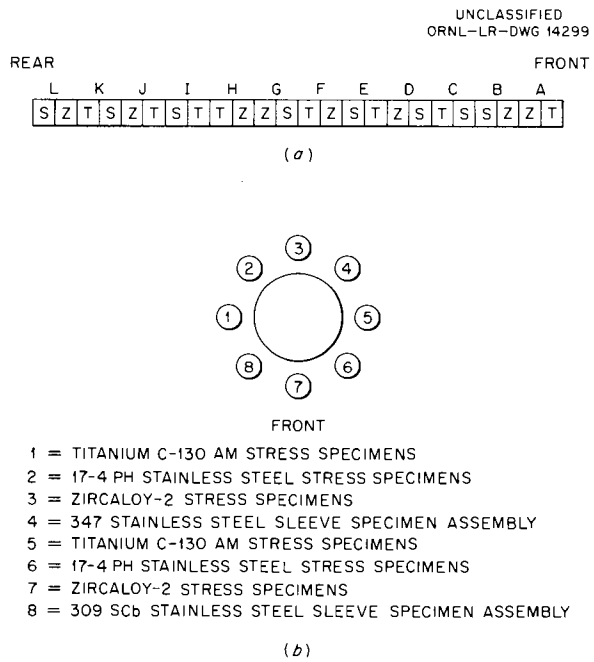

Fig. 1. Loop L-4-8 Core Specimen Distribution. (*a*) In-line and core coupon specimens. (*b*) Arrangement of sleeve and stress specimens in the core.

The other materials were used in the as-machined condition. All stress specimens were stressed to approximately 80% of the 250°C yield strength of the given material. (The values for stress and strain are shown in Table 10.)

The structure of the loop was essentially the same as that of previous loops. The circulating pump was a modified ORNL 5-gpm model of the outboard bearing type. Journals and bearings employed in this pump were of sintered aluminum oxide. This is the first in-pile loop experiment in which this bearing material has been employed. Before installation in the loop, the pump was operated for 500 hr in a test loop circulating a solution containing 0.17 *m* uranyl sulfate, 0.03 *m* copper sulfate, and 0.04 *m* sulfuric acid at 250°C and 1000 psi. At the end of this test period, no visible corrosion attack or measurable wear of the bearings could be observed. After installation in the in-pile loop, the pump failed during the preparatory operations. An examination revealed that the pump had stalled because the back bearing had moved forward and reduced the end-play. A new bearing was installed and the pump replaced in the loop. Operation of the loop in the LITR was terminated after 1637 hr when the pump failed

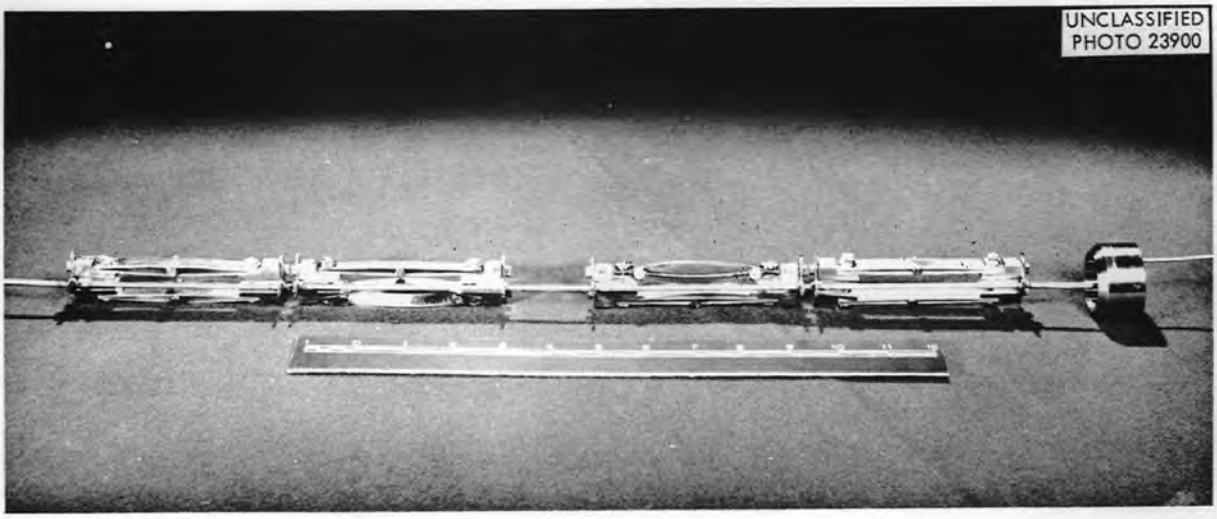

Fig. 2. Pressurizer Stress-Specimen Assemblies.

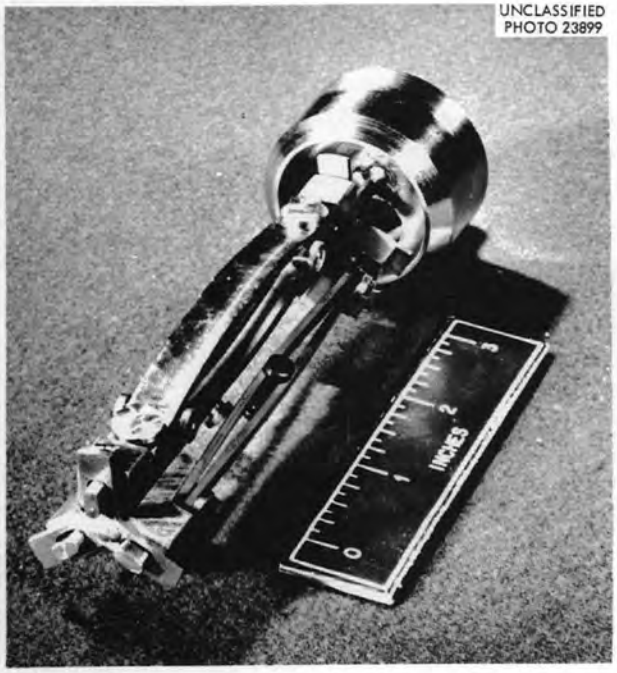

Fig. 3. Special In-Line Stress-Specimen Assemblies.

again. Subsequent examination of the pump indicated that this failure had the same cause as that observed during the preparatory operations. Despite these mechanical failures, the performance of the bearings is considered to have been excellent.

IN-PILE OPERATION

General Operating Conditions and Procedures

Loop volumes and other specifications are listed in Table 2. Loop areas are presented in Table 3. The loop preparatory operations and the results of solution analyses during these operations are summarized in Table 4.

The solution charged to the loop for in-pile operation was of the following composition: 0.17 *m* (88.8% enriched) UO_2SO_4, 0.031 *m* $CuSO_4$, 0.04 *m* H_2SO_4. A solution of the same composition was used to replace liquid withdrawn from the loop during sampling operations. This is the first loop experiment equipped with stainless steel specimens and at the same time containing a solution of this high acidity. Sulfuric acid concentrations smaller by a factor of approximately 5 were previously employed.

In-pile operation of this loop was for a period of 1637 hr. The energy output of the LITR during this time was 4377 Mwhr, and essentially all this energy was liberated at the 3-Mw level. The reactor operating schedule for the exposure is shown in Fig. 4.

The schedule for solution sampling is also shown in Fig. 4. One sample of about 2 ml was taken at each sampling. Because of the necessity of purging the sampling system with loop solution prior to removing a sample, the total volume removed from the loop at each sampling was about

TABLE 2. LOOP VOLUMES AND OTHER SPECIFICATIONS

Loop volume (including pressurizer), ml	1536
Pressurizer volume, empty, ml	520
Pressurizer volume, loaded, ml	452
Empty core volume, ml	370
Loaded core volume, ml	320
Flow rates	
Pressurizer, cc/sec	5.2
Core, gpm	5.3
In-line, gpm	5.3
Pump-bearing material	Sintered aluminum oxide
Pump-journal material	Sintered aluminum oxide
System pressure checked at, psi	1200
Minimum clearance in sample holders	
Core, in.	0.047
In-line, in.	0.048

TABLE 3. LOOP AREAS EXPOSED TO HIGH-TEMPERATURE SOLUTIONS

Component	Area Exposed (cm^2)
Type 347 Stainless Steel	
Total main circulation lines (not including pump and core)	1553
Pressurizer	
Total, 706 cm^2	
Area wetted when filled with 250 ml of solution	434
Pressurizer lines	300
Core	445
Pump	
Scroll	272
Impeller	159
8 Core corrosion sample coupons	11.37
8 In-line corrosion sample coupons	11.37
2 Pressurizer stress-corrosion specimens	39.00
2 Pressurizer stress-corrosion specimen holders	20.00
8 Core sleeve specimens	38.72
1 Core sleeve specimen rod	19.38
Total	3302.84

TABLE 3 (continued)

Component		Area Exposed (cm^2)
Type 17-4 PH Stainless Steel		
4 Core stress-corrosion specimens		78
4 Core stress-corrosion specimen holders		40
2 Special in-line stress-corrosion specimens		39
2 Special in-line stress-corrosion specimen holders		20
2 Pressurizer stress-corrosion specimens		39
2 Pressurizer stress-corrosion specimen holders		20
	Total	236
Type 309 SCb Stainless Steel		
8 Core sleeve stress-corrosion specimens		38.72
1 Core sleeve stress-corrosion specimen rod		19.38
	Total	58.10
Zircaloy-2		
8 Core corrosion sample coupons		11.20
4 Core stress-corrosion specimens		78.00
4 Core stress-corrosion specimen holders		40.00
8 In-line corrosion sample coupons		11.20
2 Special in-line stress-corrosion specimens		39.00
2 Special in-line stress-corrosion specimen holders		20.00
2 Pressurizer stress-corrosion specimens		39.00
2 Pressurizer stress-corrosion specimen holders		20.00
1 Core corrosion coupon holder		160.00
1 In-line corrosion coupon holder		160.00
	Total	578.40
Titanium		
8 Core corrosion sample coupons		11.37
4 Core stress-corrosion specimens		78.00
4 Core stress-corrosion specimen holders		40.00
8 In-line corrosion sample coupons		11.37
2 Special in-line stress-corrosion specimens		39.00
2 Special in-line stress-corrosion specimen holders		20.00
2 Pressurizer stress-corrosion specimens		39.00
2 Pressurizer stress-corrosion specimen holders		20.00
	Total	258.74

TABLE 4. ANALYSES OF SAMPLES FROM LOOP INVENTORY DURING PREPARATORY OPERATIONS*

Solution	Total Circulation Time for Each Solution (hr)	Inventory at Time of Sampling (ml)	Uranium		Copper		Nickel		Iron		Chromium		Aluminum		Chlorine		pH
			Conc (mg/ml)	Total (g)	Conc (μg/ml)	Total (mg)	Conc (μg/ml)	Total (mg)	Conc (μg/ml)	Total (mg)	Conc (μg/ml)	Total (mg)	Conc (μg/ml)	Total (mg)	Conc (μg/ml)	Total (mg)	
3% TSP (He, 90°C)	2.7	1230					2	2.5	5	6.2	<1	<1	2	2.5	<1	<1	11.8
5% HNO_3 (He, 100°C)	13.7	1210					17	20.6	79	95.6	7	8.5	16	19.4	<1	<1	
H_2O** (O_2, 250°C)	45.5	1250					<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	4.6
H_2O (O_2, 250°C)	2.3	1100					<1		<1		<1				<1		4.9
0.17 *m* UO_2SO_4 (normal) + 0.03 *m* $CuSO_4$ + 0.04 *m* H_2SO_4 (O_2, 250°C)	52.7	1040	35.6	37.0	1790	1862	107	111	8	8.3	3	3.1			3	3.1	1.49
H_2O (O_2, 250°C)	15.8	1280															

*Constituent concentrations and totals shown are not cumulative but represent the quantities present after operation with each solution.
**Pump removed and repaired.

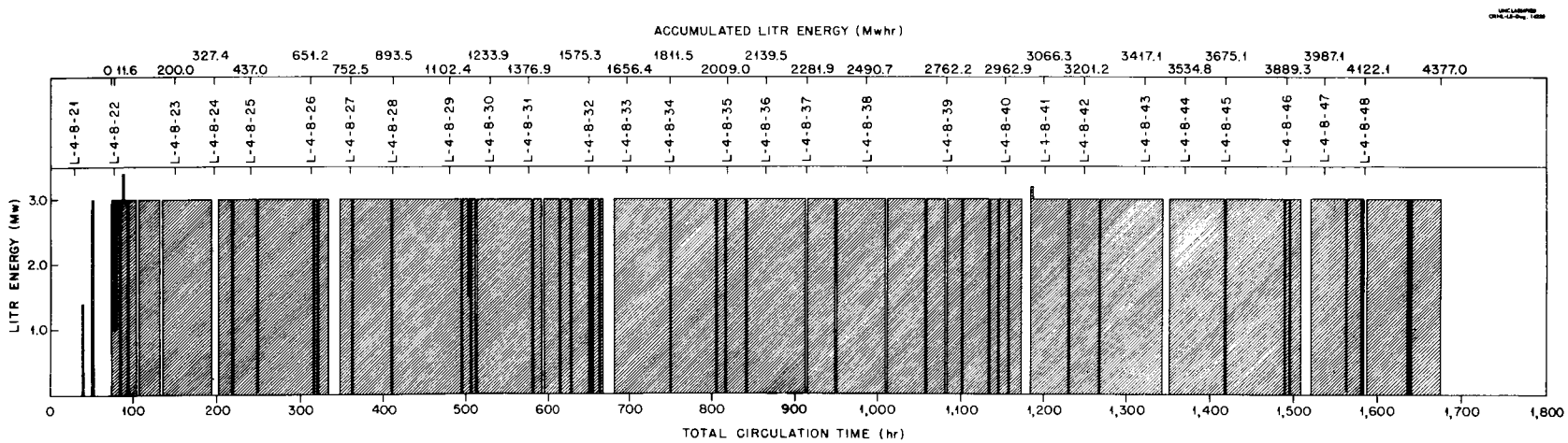

Fig. 4. LITR Operation and Sampling Schedule.

20 ml. Following the initial reactor startup, all samples were withdrawn with the reactor at power, except for samples L-4-8-32, -45, and -48, which were withdrawn after the reactor had been at zero power for 0.3, 1.5, and 1.6 hr, respectively.

Results of Solution Analyses, Oxygen Consumption, and Fission Power in Loop

The results of solution analyses for constituents other than products of irradiation are given in Table 5. As was observed during all previous experiments, the reported values for the uranium, copper, and sulfate content of the samples from this loop were found to be, in general, appreciably lower than the calculated values for the constituents. Applying dilution factors obtained by the now-standard procedure of adding lithium sulfate to the wash water and analyzing for lithium in the samples, the corrected concentrations were in most cases in near agreement with the calculated concentrations for these constituents. Several erratic analytical results provided the exceptions. The reported, corrected, and calculated values for the uranium, sulfate, and copper concentrations are compared graphically in Fig. 5. The calculated values for the other elements listed in Table 5 and the corrected values for total fissions in Table 6 have been obtained through use of the listed dilutions. The values for nickel, chlorine, aluminum, manganese, and total fissions have also been corrected for the amount of material withdrawn in sampling. No correction was applied to pH measurements.

The results of oxygen-depletion measurements are shown in Table 7. For conversion from gas volumes to pressures in the loop at operating temperature, the factor, 10 psi equivalent to 130 to 170 cc at STP, is applicable. The values for corrosion penetration listed in the final column of Table 7 were calculated under the usual assumption that all stainless steel surfaces in contact with high-temperature solutions corroded uniformly and that oxygen was lost in the corrosion of steel only.

Average values for the fission power generated in the loop were calculated from total fissions observed in the loop solution samples. The values were calculated from the corrected Cs^{137} analytical results from samples that had been allowed to cool for three months. The values are presented in Table 6 and represent the average power from the start of irradiation to the time of sampling.

The average electrical power required to maintain loop temperature with the reactor off was 919 w more than that required with the reactor operating. There was no significant change during the run. The maximum deviations from the average were +9 and −13%.

Neutron fluxes at various specimen positions in the core were determined from comparison of the induced activities of core corrosion specimens with those of type 347 stainless steel and Zircaloy-2 control specimens which had been irradiated for a known *nvt* in the LITR. Representative type 347 stainless steel specimens were taken from the core coupon array, from the sleeve-type assembly, and from the core walls. Zircaloy-2 specimens were taken from the core coupon array. The specimens were decontaminated prior to counting. Chromium-51 activity was employed for the steel measurements, and the Zr^{95}-Nb^{95} activity was employed for the Zircaloy-2 measurements. The results of these analyses are shown in Table 8. The power-density values listed are those calculated from the flux values and from the solution composition. As before, a value of 200 Mev per fission is a basis for the power-density values. Figure 6 is a plot of the neutron flux for the type 347 stainless steel and Zircaloy-2 specimens vs the axial position of the specimens in the core. The location of the leading edge of the first core coupon is designated as zero distance. As was noted with the last loop,[4] the flux values for the sleeve-type specimens and the core wall samples fit the curve with only slightly more scatter than do the values for the core coupons. This fact lends support to the conclusion previously drawn that, within experimental limits, there is no radial flux gradient in the volume occupied by the core specimens and core walls.

The value for total fission power, calculated from solution analyses for Cs^{137}, is about 18% higher than that found in the previous experiment. Approximately one-third of this difference can be accounted for by the volume of solution in the core of this loop being about 6% greater than that in the previous loop. However, an integrated value for neutron flux in the core is about 16% lower than in the previous loop. This apparent discrepancy is unaccounted for.

Uranium Balance and Radiolytic-Gas Pressure

The balance sheet for uranium charged to and recovered from the loop is shown in Table 9. The weigh tank was emptied once during operation and again at the end of operation. Material collected before the first emptying is designated as "first

TABLE 5. ANALYSES OF SAMPLES FROM LOOP INVENTORY DURING ENRICHED-SOLUTION OPERATION[a]

Sample	Total Circulation Time (hr)	Accumulated LITR Energy (Mwhr)	Inventory Volume at Time of Sample, 25°C (ml)	Lithium[i] (mg/ml)	Sample Dilution Factor[b]	Uranium			Sulfate			Copper			Chromium		Nickel		Chlorine		Iron		Zirconium		Aluminum		Manganese		pH	Specific Gravity
						Rep (mg/ml)	Cor[d] (mg/ml)	Calcd[c] (mg/ml)	Rep (mg/ml)	Cor[k] (mg/ml)	Calcd[c] (mg/ml)	Rep (mg/ml)	Cor[d] (mg/ml)	Calcd[e] (mg/ml)	Cor[d] (mg/ml)	Calcd Total[f] (g)	Cor[d] (mg/ml)	Calcd Total[g] (g)	Cor[d] (mg/ml)	Calcd Total[g] (g)	Cor[d] (mg/ml)	Calcd Total[f] (g)	Cor[d] (mg/ml)	Calcd Total[f] (g)	Cor[d] (mg/ml)	Calcd Total[g] (g)	Cor[d] (mg/ml)	Calcd Total[g] (g)		
L-4-8-20[j]	0	0	1091	(ND)	0	38.26	38.26	38.26	24.61	24.61	24.61	1.939	1.939	1.939	0.050	0.055	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	1.30	1.061
L-4-8-21[b]	29.8	0	1091	0.033	1.04	31.5	32.8	38.3	21.8	22.5	24.6	6.91	7.16	1.94	0.013	0.014	0.040	0.043	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	1.50	
Reactor started up	74.4	0	1091																											
L-4-8-22	78.0	11.6	1091	0.099	1.12	31.5	35.3	38.3	20.9	22.5	24.6	2.17	2.42	1.94	0.032	0.035	0.095	0.104	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	(ND)	1.40	
L-4-8-23	150.5	200.0	1091	0.122	1.15	31.3	36.0	38.2	22.0	24.2	24.6	1.95	2.24	1.94	0.022	0.024	0.470	0.515	(ND)	(ND)	0.030	0.033	0.016	0.018	(ND)	(ND)	0.053	0.058	1.45	
L-4-8-24	197.4	327.4	1092	0.131	1.16	32.5	37.7	38.2	22.0	24.5	24.6	2.00	2.32	1.94	0.020	0.022	0.655	0.722	(ND)	(ND)	0.015	0.016	0.012	0.013	(ND)	(ND)	0.081	0.089	1.50	
L-4-8-25	240.9	437.0	1092	0.119	1.14	38.8	44.2	38.2	23.1	25.4	24.6	2.40	2.74	1.94	0.016	0.018	0.802	0.891	(ND)	(ND)	0.016	0.015	0.038	0.042	(ND)	(ND)	0.117	0.129	1.60	
L-4-8-26	313.1	651.2	1091	0.009	1.01	33.1	33.4	38.2	22.8	22.9	24.6	2.15	2.18	1.94	0.005	0.006	0.497	0.567	(ND)	(ND)	0.035	0.038	0.032	0.035	(ND)	(ND)	0.126	0.141	1.45	
L-4-8-27	360.9	752.5	1091	0.048	1.05	36.3	38.1	38.2	22.4	23.2	24.6	1.89	1.99	1.94	0.011	0.012	0.922	1.037	(ND)	(ND)	0.021	0.023	0.081	0.089	(ND)	(ND)	0.118	0.135	1.80	
L-4-8-28	410.9	893.5	1091	0.038	1.04	36.1	37.5	38.2	22.3	22.9	24.6	1.92	2.00	1.94	0.021	0.023	0.933	1.060	(ND)	(ND)	0.037	0.040	0.032	0.035	(ND)	(ND)	0.101	0.116	1.60	
L-4-8-29	481.0	1102.4	1091	0.031	1.03	33.6	34.6	38.2	22.7	23.3	24.6	1.58	1.64	1.94	0.003	0.003	0.859	0.990	(ND)	(ND)	0.018	0.020	0.071	0.078	(ND)	(ND)	0.086	0.101	1.70	
L-4-8-30	529.8	1233.9	1091	0.037	1.04	38.1	39.6	38.2	23.1	23.7	24.6	2.10	2.18	1.94	(ND)	(ND)	0.939	1.086	(ND)	(ND)	0.047	0.051	0.021	0.023	(ND)	(ND)	(ND)	(ND)	1.50	
L-4-8-31	577.4	1376.9	1092	0.054	1.06	36.2	38.4	38.2	22.9	23.9	24.6	1.52	1.61	1.94	(ND)	(ND)	0.838	0.987	(ND)	(ND)	0.034	0.037	0.031	0.034	(ND)	(ND)	0.060	0.074	1.80	
L-4-8-32[b]	651.2	1575.3	1091	0.037	1.04	35.1	36.5	38.2	24.9	25.7	24.5	1.56	1.62	1.93	(ND)	(ND)	0.919	1.087	(ND)	(ND)	0.019	0.021	0.053	0.058	(ND)	(ND)	(ND)	(ND)	1.70	
L-4-8-33	697.2	1656.4	1091	0.037	1.04	37.7	39.2	38.2	22.6	23.2	24.5	2.35	2.44	1.93	(ND)	(ND)	0.861	1.034	(ND)	(ND)	0.021	0.023	0.041	0.045	(ND)	(ND)	0.127	0.148	1.85	
L-4-8-34	748.8	1811.5	1092	0.031	1.03	39.7	40.9	38.2	21.8	22.3	24.5	1.62	1.67	1.93	0.026	0.028	1.093	1.297	(ND)	(ND)	0.025	0.027	0.018	0.020	(ND)	(ND)	0.123	0.145	1.65	
L-4-8-35	818.7	2009.0	1091	0.047	1.05	43.9	46.1	38.2	24.4	25.4	24.5	1.71	1.80	1.93	(ND)	(ND)	1.004	1.214	(ND)	(ND)	0.028	0.031	0.056	0.061	(ND)	(ND)	0.134	0.158	1.60	
L-4-8-36	865.0	2139.5	1091	0.038	1.04	42.9	44.6	38.2	23.7	24.5	24.5	2.08	2.17	1.93	0.016	0.018	1.087	1.316	(ND)	(ND)	0.022	0.024	0.029	0.031	(ND)	(ND)	0.145	0.172	1.70	
L-4-8-37	914.6	2281.9	1091	0.035	1.03	33.8	34.8	38.2	24.1	24.7	24.5	1.52	1.57	1.93	0.030	0.033	0.963	1.194	(ND)	(ND)	0.038	0.042	0.057	0.062	(ND)	(ND)	0.135	0.203	1.60	
L-4-8-38	986.2	2490.7	1092	0.027	1.03	36.3	37.4	38.2	25.2	25.7	24.5	1.91	1.97	1.93	0.012	0.013	1.062	1.313	(ND)	(ND)	0.019	0.021	0.032	0.035	(ND)	(ND)	0.037	0.057	1.60	
L-4-8-39	1082.5	2762.2	1092	0.033	1.04	37.0	38.5	38.2	24.4	25.1	24.5	1.52	1.57	1.93	0.028	0.031	1.311	1.599	(ND)	(ND)	0.010	0.011	0.024	0.026	(ND)	(ND)	(ND)	(ND)	1.70	
L-4-8-40	1153.0	2962.9	1092	0.039	1.04	37.4	38.9	38.2	24.3	25.0	24.5	1.48	1.55	1.93	0.025	0.027	1.399	1.701	(ND)	(ND)	0.013	0.014	0.013	0.014	(ND)	(ND)	0.132	0.161	1.65	
L-4-8-41	1200.9	3066.3	1092	0.034	1.04	39.0	40.5	38.2	22.6	23.2	24.5	1.66	1.72	1.93	(ND)	(ND)	1.070	1.358	(ND)	(ND)	0.005	0.006	0.037	0.040	(ND)	(ND)	0.144	0.176	1.70	
L-4-8-42	1248.9	3201.2	1093	0.036	1.04	34.6	35.9	38.1	22.4	23.0	24.5	1.68	1.74	1.93	0.015	0.016	1.037	1.336	(ND)	(ND)	0.019	0.021	0.020	0.022	(ND)	(ND)	(ND)	(ND)	1.75	
L-4-8-43	1321.3	3417.1	1092	0.030	1.03	37.3	38.5	38.1	22.3	22.8	24.5	1.73	1.79	1.93	(ND)	(ND)	1.045	1.356	(ND)	(ND)	0.024	0.026	0.024	0.026	(ND)	(ND)	0.163	0.198	1.80	
L-4-8-44	1369.8	3534.8	1092	0.172	1.22	30.0	36.6	38.1	21.9	25.2	24.5	1.32	1.61	1.93	(ND)	(ND)	1.316	1.665	(ND)	(ND)	0.037	0.040	0.028	0.031	(ND)	(ND)	0.122	0.156	1.80	
L-4-8-45[b]	1418.0	3675.1	1092	0.167	1.21	29.8	36.1	38.1	19.6	22.3	24.5	1.49	1.81	1.93	0.024	0.026	1.184	1.537	(ND)	(ND)	0.039	0.043	0.011	0.012	(ND)	(ND)	0.147	0.185	1.60	
L-4-8-46	1490.9	3889.3	1092	0.179	1.23	28.8	35.4	38.1	19.9	23.0	24.5	1.38	1.70	1.93	(ND)	(ND)	1.069	1.425	(ND)	(ND)	0.021	0.023	0.042	0.046	(ND)	(ND)	0.169	0.210	1.85	
L-4-8-47	1536.8	3987.1	1092	0.153	1.19	27.6	32.9	38.1	20.9	23.7	24.5	1.32	1.58	1.93	(ND)	(ND)	1.057	1.425	(ND)	(ND)	0.025	0.027	0.019	0.021	(ND)	(ND)	0.161	0.204	1.70	
L-4-8-48[b]	1585.0	4122.1	1091	0.162	1.21	27.2	32.8	38.1	20.1	22.9	24.5	1.13	1.36	1.93	(ND)	(ND)	1.252	1.650	(ND)	(ND)	0.029	0.032	0.011	0.012	(ND)	(ND)	0.144	0.187	1.80	

[a] Where no values are given, either an analysis was not requested or the analytical results were not reliable. ND, not detected.
[b] Dilution factors calculated on lithium concentration found in sample.
[c] Determined from calculated uranium, sulfate, and inventory balances.
[d] (Reported concentration) × (dilution factor).
[e] Original concentration × calculated uranium concentration/original uranium concentration.
[f] (Reported concentration) × (dilution factor) × (inventory volume).
[g] (Reported concentration corrected for sample dilution and amounts withdrawn in previous samples) × (inventory volume).
[h] Sample taken with reactor down.
[i] Wash water contained Li_2SO_4 at 0.0684 *M*.
[j] Original and makeup solutions of same composition.
[k] (Reported concentration) × (dilution factor); corrected for SO_4^{--} from Li_2SO_4.

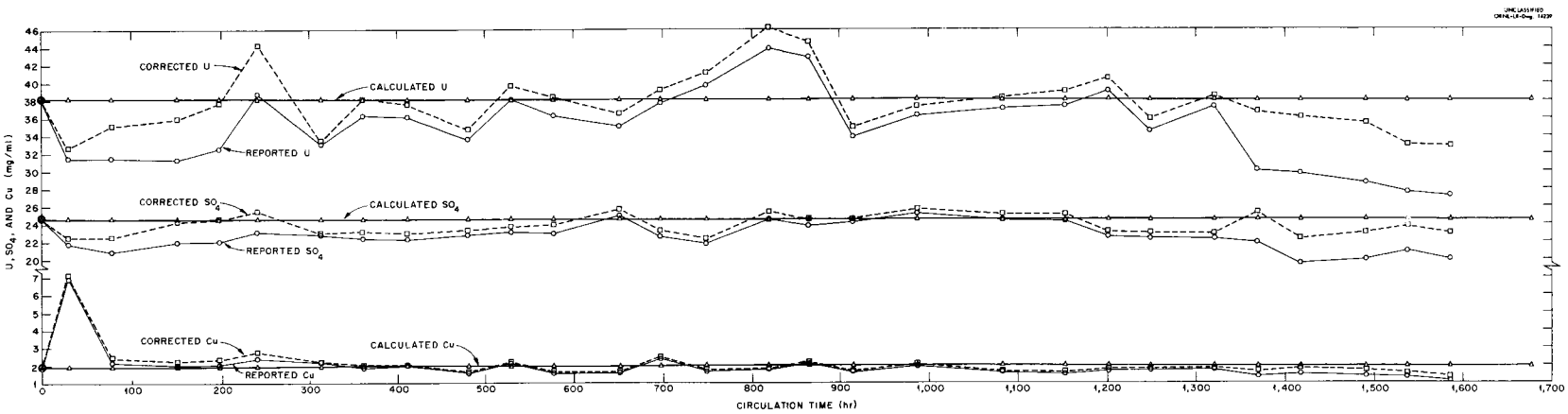

Fig. 5. Comparison of Reported and Calculated U, SO_4, and Cu Concentrations for Enriched-Solution Operations.

TABLE 6. FISSIONS IN LOOP SOLUTION

Sample No.	Acumulated LITR Energy (Mwhr)	Inventory Volume at Time of Sample (ml at 25°C)	Calculated Uranium Concentration (mg/ml)	Total Fissions per ml × 10^{-16}		Total Fission Power in Loop Solution at 3 Mw (w)
				Analysis	Corrected*	
L-4-8-23	200.0	1091	38.2	0.336	0.384	559
L-4-8-24	327.4	1091	38.2	0.543	0.636	561
L-4-8-25	437.0	1092	38.2	0.709	0.829	546
L-4-8-26	651.2	1092	38.2	1.11	1.15	589
L-4-8-27	752.5	1091	38.2	1.30	1.42	653
L-4-8-28	893.5	1091	38.2	1.75	1.90	748
L-4-8-29	1102.4	1091	38.2	2.07	2.25	743
L-4-8-30	1233.9	1091	38.2	2.27	2.51	574
L-4-8-31	1376.9	1091	38.2	2.54	2.88	593
L-4-8-32	1575.3	1092	38.2	2.95	3.31	594
L-4-8-33	1656.4	1091	38.2	3.14	3.56	605
L-4-8-34	1811.5	1091	38.2	3.18	3.65	563
L-4-8-35	2009.0	1092	38.2	3.42	4.01	558
L-4-8-36	2139.5	1091	38.2	3.52	4.15	539
L-4-8-37	2281.9	1091	38.2	4.50	5.20	635
L-4-8-38	2490.7	1091	38.2	4.58	5.33	595
L-4-8-39	2762.2	1092	38.2	5.41	6.31	636
L-4-8-40	2962.9	1092	38.2	5.77	6.83	640
L-4-8-41	3066.3	1092	38.2	5.70	6.86	614
L-4-8-42	3201.2	1093	38.1	5.90	7.16	614
L-4-8-43	3417.1	1091	38.1	6.82	8.17	658
L-4-8-44	3534.8	1092	38.1	5.95	8.53	661
L-4-8-45	3675.1	1092	38.1	6.16	8.86	659
L-4-8-46	3889.3	1092	38.1	6.50	9.54	669
L-4-8-47	3987.1	1092	38.1	6.57	9.50	647
L-4-8-48	4122.1	1091	38.1	6.84	10.1	660
						Av 620

*Corrected to include amounts withdrawn in previous samples and for sample dilution.

TABLE 7. OXYGEN CONSUMPTION IN LOOP L-4-8

Remarks	Sample No.	LITR Energy (Mwhr)	Total Solution Circulation Time (hr)	O_2 Additions to Loop (cc at STP)	O_2 Withdrawn from Loop* (cc at STP)	Total O_2 Charged to Loop Less O_2 Withdrawn in Sampling (cc at STP)	O_2 Volume at Time of Sample (cc at STP)	O_2 Consumed Since Last Sample (cc at STP)	Total O_2 Consumed (cc at STP)	Calculated Corrosion Penetration of Type 347 Stainless Steel (mils)
Original fill		0	0	1389	0	1389	1389		0	
O_2 addition L-4-8-2		0	12.9	393	0	1782	1748		34	
	L-4-8-21	0	29.8	0	0	1782	1713	69	69	0.003
Reactor started up		0	38.6	0	6	1776				
Reactor at 3 Mw			75.1	0	0	1776	1617		159	
	L-4-8-22	11.6	78.0	0	0	1776	1513	194	263	0.012
O_2 addition L-4-8-3			132.5	1315	5	3086	1737		1349	
	L-4-8-23	200.0	150.5	0	0	3086	1460	1363	1626	0.07
	L-4-8-24	327.4	197.4	0	5	3081	748	707	2333	0.11
O_2 addition L-4-8-4			217.8	931	3	4009	1512		2497	
	L-4-8-25	437.0	240.9	0	0	4009	1367	309	2642	0.12
	L-4-8-26	651.2	313.1	0	5	4004	945	417	3059	0.14
	L-4-8-27	752.5	360.9	0	4	4000	808	133	3192	0.15
	L-4-8-28	893.5	410.9	0	3	3997	708	97	3289	0.15
	L-4-8-29	1102.4	481.0	0	3	3994	610	95	3384	0.15
	L-4-8-30	1233.9	529.8	0	2	3992	538	70	3454	0.16
	L-4-8-31	1376.9	577.4	0	2	3990	465	71	3525	0.16
O_2 addition L-4-8-5			582.4	1097	2	5085	1553		3532	
	L-4-8-32	1575.3	651.2	0	0	5085	1427	133	3658	0.17
	L-4-8-33	1656.4	697.2	0	5	5080	1354	68	3726	0.17
	L-4-8-34	1811.5	748.8	0	6	5074	1295	21	3779	0.17
	L-4-8-35	2009.0	818.7	0	6	5068	1219	70	3849	0.18
	L-4-8-36	2139.5	865.0	0	5	5061	1100	112	3961	0.18
	L-4-8-37	2281.9	914.6	0	5	5056	993	102	4063	0.19
	L-4-8-38	2490.7	986.2	0	4	5052	868	121	4184	0.19
	L-4-8-39	2762.2	1082.5	0	4	5048	694	170	4354	0.20
	L-4-8-40	2962.9	1153.0	0	3	5045	566	125	4479	0.20
	L-4-8-41	3066.3	1200.9	0	3	5042	482	81	4560	0.21
O_2 addition L-4-8-6			1230.7	1008	2	6048	1436		4612	
	L-4-8-42	3201.2	1248.9	0	0	6048	1398	90	4650	0.21
	L-4-8-43	3417.1	1321.3	0	6	6042	1242	150	4800	0.22
	L-4-8-44	3534.8	1369.8	0	5	6037	1126	111	4911	0.22
	L-4-8-45	3675.1	1418.0	0	5	6032	1012	109	5020	0.23
	L-4-8-46	3889.3	1490.9	0	4	6028	842	170	5190	0.24
	L-4-8-47	3987.1	1536.8	0	4	6024	745	97	5287	0.24
	L-4-8-48	4122.1	1585.0	0	3	6021	647	98	5385	0.24
End of run		4377.0	1675.6	0	3	6018	562	85	5470	0.25

*Calculated amount removed as O_2 dissolved in sample.

TABLE 8. INDUCED ZIRCONIUM-NIOBIUM AND CHROMIUM ACTIVITY IN SPECIMENS

Specimen No.	Cleaned Weight When Counted (g)	Relative Zr-Nb Activity (0.76-Mev gamma) (counts/min/coupon)	Relative Zr-Nb Activity (0.76-Mev gamma) (counts/min/g)	Relative Cr^{51} Activity (counts/min/coupon)	Relative Cr^{51} Activity (counts/min/g)	Exposure Time for Specimens (hr) (1 hr = 3 Mwhr)	Cooling Time Before Analysis (hr)	Neutron Flux at 3 Mw (10^{12} neutrons/cm^2/sec)	Power Density at 3 Mw* (w/ml)
Core Corrosion Sample Coupons									
Type 347 stainless steel									
1335 A	0.8822			2.22	2.52	1459	2424	2.72	3.49
1337 A	0.9131			2.10	2.30	1459	2424	2.49	3.19
1338 A	0.8612			1.40	1.63	1459	2424	1.76	2.26
1340 A	0.9546			0.90	0.94	1459	2424	1.02	1.31
1341 A	0.9498			0.78	0.82	1459	2424	0.89	1.14
Zircaloy-2									
Z-11	0.7432	8.36	11.25			1459	2424	3.72	4.78
Z-18	0.7485	6.40	8.55			1459	2424	2.83	3.63
Z-22	0.7318	5.19	7.09			1459	2424	2.35	3.01
Z-28	0.7424	3.90	5.25			1459	2424	1.74	2.23
Z-30	0.7586	2.75	3.63			1459	2424	1.20	1.54
Sleeve-Type Corrosion Specimens									
Type 347 stainless steel									
S-24	0.8711			1.72	1.97	1459	2424	2.13	2.74
S-25	0.8813			1.47	1.67	1459	2424	1.80	2.31
S-26	0.8947			1.29	1.44	1459	2424	1.56	2.00
S-27	0.8926			1.04	1.17	1459	2424	1.26	1.62
S-28	0.8981			0.98	1.09	1459	2424	1.18	1.51
S-30	0.9062			0.57	0.63	1459	2424	0.68	0.87
Core Wall and Cap Specimens									
Type 347 stainless steel									
L-4-8-A	0.2768			1.37	4.95	1459	2424	5.35	6.86
L-4-8-F	0.3039			0.86	2.83	1459	2424	3.06	3.93
L-4-8-E	0.2441			0.27	1.11	1459	2424	1.20	1.53

Control Specimens

Specimen No.	Cleaned Weight When Counted (g)	Relative Zr-Nb Activity (0.76-Mev gamma) (counts/min/coupon)	Relative Zr-Nb Activity (0.76-Mev gamma) (counts/min/g)	Relative Cr^{51} Activity (counts/min/coupon)	Relative Cr^{51} Activity (counts/min/g)	Exposure Time for Controls (hr)	Cooling Time Before Analysis (hr)	Neutron Flux (10^{13} neutrons/cm^2/sec)
Type 347 stainless steel								
1384 A	1.1497			1.00	0.87	31.4	1944	1.27
Zircaloy-2								
Z	0.7889	1.00	1.27			31.4	1944	1.27

*Uranium concentration: 38.19 mg/ml, 88.78% enrichment.

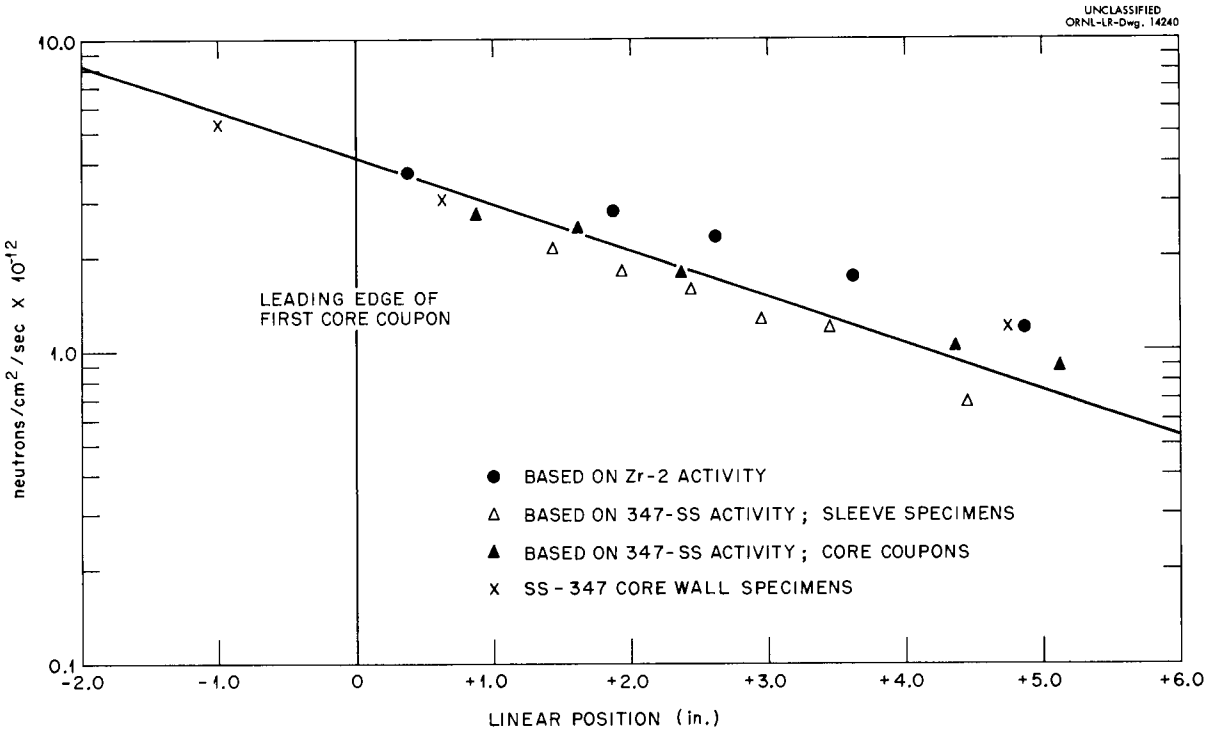

Fig. 6. Neutron Flux in the Core vs Linear Position.

TABLE 9. URANIUM BALANCE

Source	Solution Weight (g)	Specific Gravity	Solution Volume (ml)	Uranium Concentration by Analysis (mg/ml)	Weight of Uranium (g)
		Charged to Loop			
1. Original solution charged to loop	1166.7	1.061	1099.6	38.26	42.07
2. Solution added during operation	579.3	1.061	546.0	38.26	20.89
				Total	62.96
		Recovered from Loop			
First-weigh-tank sample sent to laboratory			4.0	1.95	0.01
First-weigh-tank contents after sampling	6785*	1.0**	6785	1.95	13.23
Second-weigh-tank sample sent to laboratory			8.85	5.84	0.05
Second-weigh-tank contents after sampling	8208*	1.0**	8208	5.84	47.93
Loop inventory sample sent to laboratory			66.15	43.86–27.23	2.27
				Total	63.49

*From weigh-tank reading.

**Assumed.

weigh tank"; that collected afterward as "second weigh tank." The value for uranium recovered from the loop is in excellent agreement with the value for that charged to the loop.

The steady-state pressure of radiolytic gas during this experiment was observed to decrease from an initial value of about 9 psi to a final value of about 5 psi.

Corrosion Indicated by Nickel, Oxygen, and Manganese Data

Values for corrosive penetration of type 347 stainless steel were calculated which correspond to the amount of nickel and manganese found in the loop solution samples (Table 5) and to the oxygen-depletion data (Table 7). All three methods of calculation were based on the assumption that all steel surfaces in contact with high-temperature solution corroded uniformly and that steel surfaces in the cool rotor region of the pump did not corrode. It was also assumed that oxygen was consumed only in the oxidation of steel. Calculated values are plotted against circulation time in Fig. 7. Other quantities of interest are shown on additional scales. The curves are of the same general type as those obtained for previous experiments, showing a high initial corrosion rate which leveled off to a much lower and fairly constant rate after the first 300 hr of exposure in the reactor. As calculated from the oxygen data, the corrosion rate during the first 300 hr after reactor startup was 4.0 mpy. During the final 1336 hr the average rate was 0.7 mpy.

REMOTE DISMANTLING AND INSPECTION

Dismantling

The loop was dismantled without any significant difficulties. Various components, including the core, two in-line sample holders, the pressurizer, pressurizer heater, and a sample of the piping, were transferred to the Solid State Division hot cells for disassembly and inspection. The remainder of the loop package was sent to the burial ground.

Examination of the circulation pump in the dismantling cell revealed that the rotor could be freed by using a long rod inserted through the inlet pipe and driving the rotor assembly back into the stator. This indicated, as mentioned previously, that the pump had stalled because the rear bearing had moved forward.

Qualitative Results of Inspection and Evaluation

As with previous loop experiments, all stainless steel surfaces outside the core were covered with a heavy rustlike scale with no apparent localized attack on any of the components inspected. The quantity of scale in the gas phase of the pressurizer was less than that in the solution phase. There was no visual indication in the pressurizer region of any changes in the scale character other than quantity.

All coupons in the in-line position were covered with a heavy, flaky scale, which was similar in appearance to the scale covering the stressed specimens in the special in-line position. Considerable difficulty was again encountered in defilming the in-line coupons by the standard cathodic treatment in an inhibited 5% sulfuric acid solution. The titanium coupons were defilmed more readily than the stainless steel and much more readily than the Zircaloy-2 coupons. The Zircaloy-2 coupons, in fact, were never completely defilmed, as weight gains were recorded after the final defilming. The defilming characteristics of the stressed specimens from the special in-line position and from the pressurizer were similar to those of the in-line coupons. A photograph of the inside surface of the tapered in-line holder is shown in Fig. 8. The heavy, flaky nature of the scale is apparent in the region where it had buckled and broken off. The smooth, thin, adherent film on the Zircaloy-2 holder under the scale is also apparent in this photograph.

Figure 9 is a photograph of the core assembly as it was removed from the loop before disassembly. This view shows three of the six stress assemblies, the outside of the core coupon holder, and the stainless steel spiders and clamping bands. It will be noted that all stainless steel components are covered with a rustlike deposit. This was also true of the two rods containing sleeve samples, which were also in this core region. All components of the type 17-4 PH stainless steel stress assemblies were also covered with a rustlike film, apparently varying in thickness inversely to the flux level. There was none of the discoloration in the fulcrum regions seen previously.[4] The Zircaloy stress assemblies were covered with a thin dark film on all surfaces.

The two rod-and-sleeve specimen assemblies were somewhat difficult to disassemble remotely,

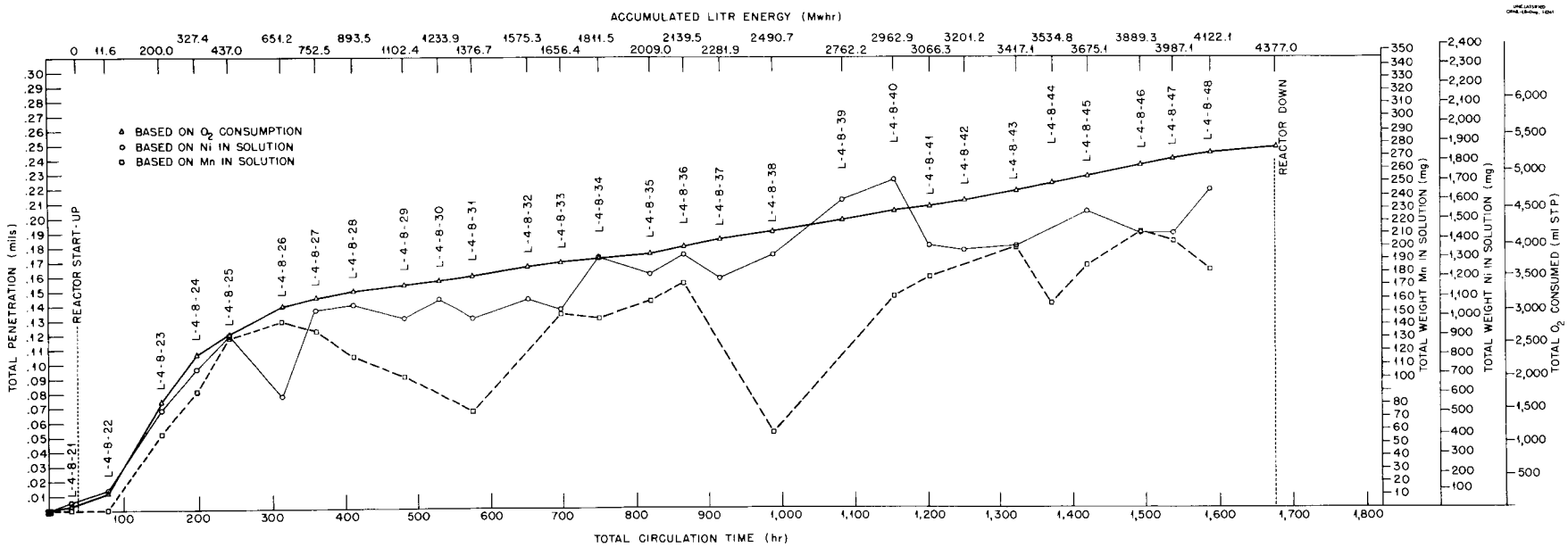

Fig. 7. Over-all Type Stainless Steel Corrosion Penetration During Enriched Solution Operation.

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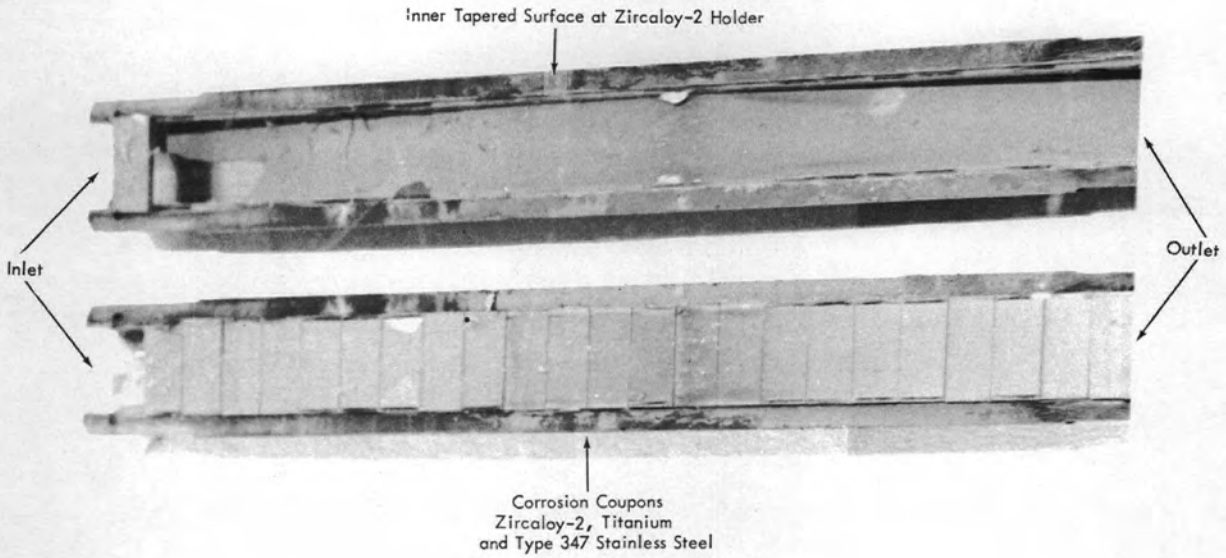

Fig. 8. In-Line Coupon Assembly.

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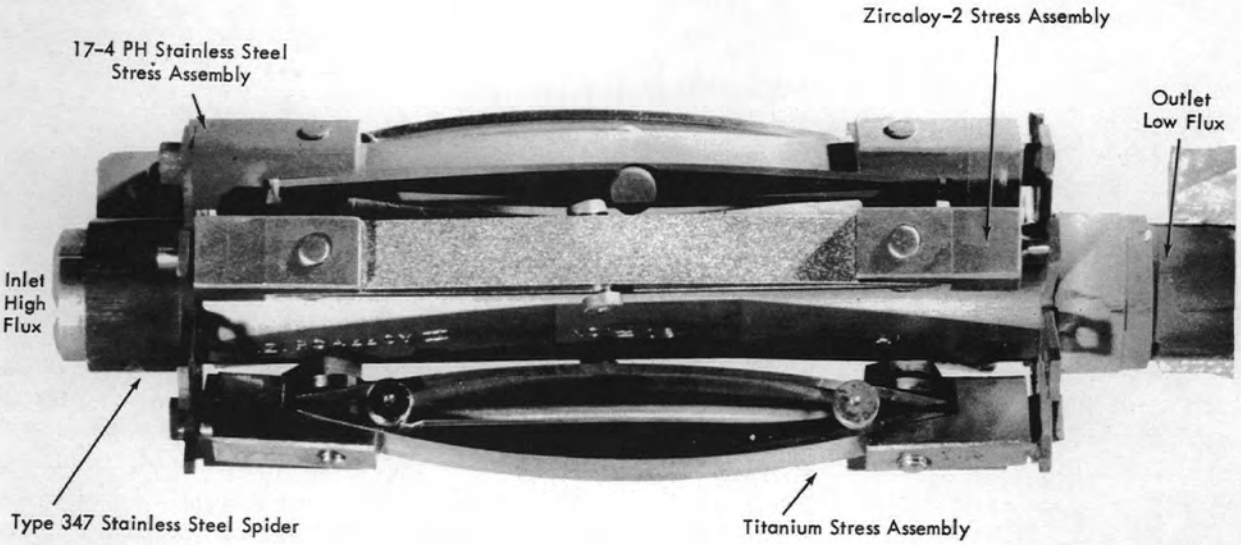

Fig. 9. Core Specimen Assembly.

apparently because an accumulation of corrosion products tended to seal the sleeves to the rod. This sealing was particularly pronounced for the type 309 SCb assembly. All the specimens except two of the type 309 SCb sleeves were successfully removed with a screw-jack arrangement such as that used with the coupled specimen assemblies of loop EE.[4] The two type 309 SCb sleeves were finally removed by first soaking the assembly in carbon tetrachloride overnight and then tapping on the sleeves as gently as possible. Some small mechanical damage of the specimens resulted from this procedure. Increased clearance between rod and specimen in future assemblies should alleviate this problem. After being defilmed, the type 347 sleeve specimens which were in the highest flux were found to be marked with longitudinal grooves so that the surface resembled in appearance the bark of a hickory tree. No such grooves were found on the type 309 SCb sleeves.

Figure 10 is a photograph of the core coupon holder and some of the coupons in the core array. Unfortunately, some of the coupons were dislodged in disassembly and are not shown in this photograph. It can be seen that the exterior surface of the Zircaloy-2 holder is essentially free from any bulk scale in the higher flux regions in front of the rear spider. The interior surfaces of the holder did have some very thin rustlike deposit in the highest flux region, and this deposit was progressively heavier with decreasing flux.

The Zircaloy-2 coupons in the high-flux end of the core array were covered with a dark granular scale. After defilming, the granular nature was found to be associated with the rough etched surface of the metal. A darker colored scale was found on the other Zircaloy-2 coupons in the core array and on all titanium coupons in the higher flux regions, with the exception of the coupon in the highest flux position. The titanium coupon in the highest flux was essentially free from any scale. All the stainless steel coupons and the titanium coupons in the low-flux end of the core array were covered with the rust-colored scale typical of the remainder of the loop. The amount of this scale was again inversely proportional to the flux. The stainless steel specimens in the higher flux regions were severely pickled in appearance, particularly those in the high-velocity regions. The clamped edges of these coupons were protected, as has been the case with previously reported stainless steel coupons.

A brief description of each specimen from the loop is given in Table 10.

Core coupons T-31, Z-17, 1336A, T-34, 1339A, Z-23, Z-32, and 1342A, together with two sleeve specimens from each of the rod-and-sleeve assemblies and pieces from the core cap, pressurizer, pressurizer heater, and the loop piping, have been submitted for metallographic examination. All the stressed specimens from the various positions in the loop will also be examined by the Metallography Group, particularly for any evidence of stress corrosion.

All the remaining stainless steel and Zircaloy-2 coupons from the core, the remaining sleeve specimens, and three portions of the stainless steel core were decontaminated chemically, weighed, and transferred to the Analytical Chemistry Division for activation analysis. These data are listed in Table 8.

Quantitative Results of Inspection and Evaluation

Sample weight data, together with other pertinent information, are presented in Table 10. Two different values for corrosion penetration were calculated for each specimen from the weight-change data. One value is based on the exposed area of the specimen, and the other is based on the total area. Two different corrosion-rate values are listed for each penetration value. One was computed with total circulation time as a basis, and the other with radiation time as a basis. The value for the neutron flux to which a given core specimen was exposed during operation and the corresponding fission power density in the solution are also listed in the table. The flux values are those which correspond to the specimen position in the core as shown by the flux-position plot in Fig. 6. The values for the stress specimens were obtained by averaging logarithmically the flux values at the ends of the specimen.

DISCUSSION OF RESULTS

Zircaloy-2

The corrosion-rate values from Table 10 for Zircaloy-2 core holder coupons are plotted in Fig. 11 as a function of the fission power density to which the specimens were exposed. The rate values employed are those computed by using exposed area and radiation time as bases. Data obtained with similarly located specimens in previous experiments are included in Fig. 11 for comparison. An apparent leveling-off of the irradiation

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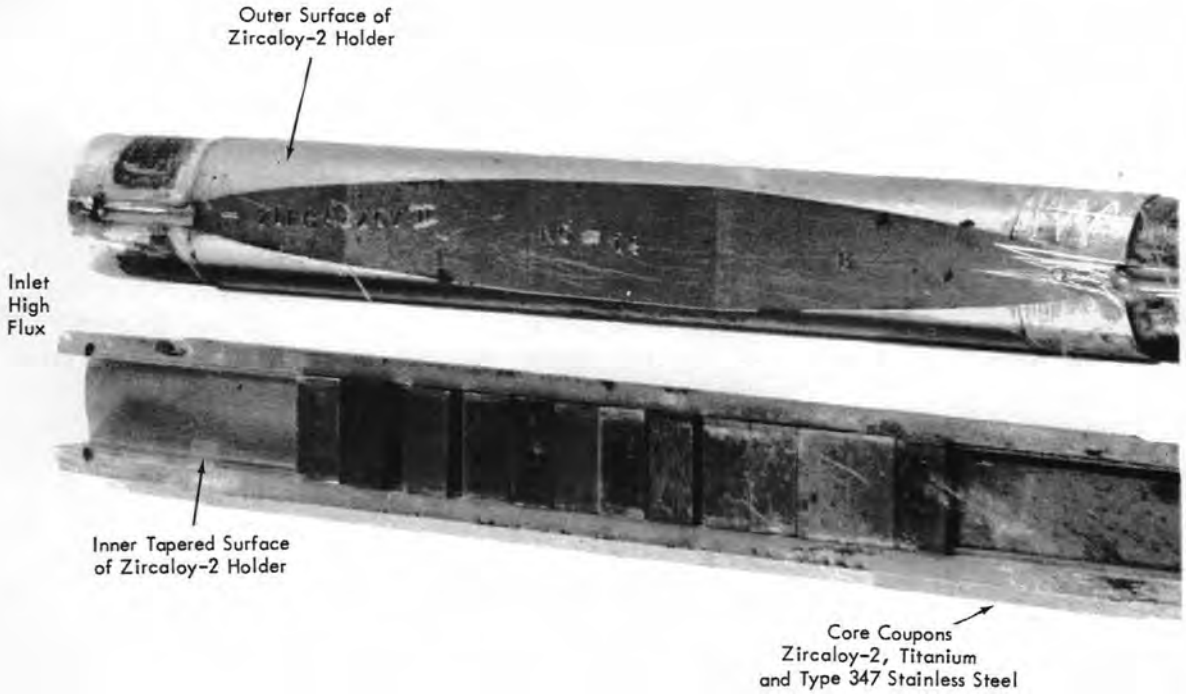

Fig. 10. Core Coupon Assembly.

effect at high power densities was noted previously for experiment GG. The results of the present experiment indicate a similar effect. This apparent leveling-off is illustrated more clearly in Fig. 12, in which the same corrosion data are plotted against the square root of the power density. Reasonably good straight lines can be drawn through each set of data in Fig. 12. Except for the data from experiment FF, the slopes of the lines are also in reasonable agreement. Some spread in the values for the corrosion rate determined for a given power density in the different experiments is also apparent in Fig. 12. No explanation of this spread is offered except to note that the experimental conditions for the various experiments also varied. The more obvious differences for these four experiments are shown in Table 11.

As mentioned previously, the Zircaloy-2 specimens exposed in portions of the loop outside the core could not be defilmed completely, and, in each case, weight gains were recorded after the final defilming.

Titanium 55AX

Corrosion rate values for the titanium 55AX core coupons are plotted in Fig. 13 in the same manner as the Zircaloy-2 results are plotted in Fig. 11. Previous titanium results from loop EE are also presented for comparison. In contrast to the previous results, there is no evidence in the present results of an effect of solution velocity on the attack. There is also no clear evidence for an effect of power density.

As shown in Table 10, the average corrosion rate of the in-line titanium 55AX coupons was 0.2 mpy, and the maximum for a given specimen was 0.5 mpy. There was no apparent effect of velocity on the attack of the in-line specimens. It might be pointed out in connection with these low corrosion-rate values that the weighing uncertainty of ±0.2 mg corresponds to a corrosion

TABLE 10. DATA FOR CORROSION SPECIMENS

Sample No.	Position	Average Flow Velocity Across Specimen (fps)	Weight Data: Initial (g)	Weight Data: As Removed (g)	Weight Data: Defilmed (g)	Weight Data: Change (mg)	Exposed Sample Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Exposed Area) (mpy): 1676 hr	Corrosion Rate* (Exposed Area) (mpy): 1459 hr	Total Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Total Area) (mpy): 1676 hr	Corrosion Rate* (Total Area) (mpy): 1459 hr	Distance from Front of First Specimen to Center of Specimen (in.)	Neutron Flux at Specimen Locations at 3 Mw (neutrons/cm^2/sec × 10^{-12})	Power Density at Specimen Locations at 3 Mw (w/ml)	Strain (μin./in.)	Stress (psi)	Appearance: As Removed	Appearance: Defilmed
I. 24 CORE SAMPLE COUPONS																					
A. 8 Type 347 Stainless Steel Coupons																					
1335 A	4	11.9	0.9465	0.8833	0.8829	−63.6	.4	1.40	2.23	11.64	13.37	2.1	1.49	7.76	8.91	0.875	3.10	3.98			Rust-colored rippled scale on all surfaces	Heavily pickled surface with increased attack along one edge; some film retained
1336 A	5	13.2	0.9503	0.9004	0.8994	−50.9	1.0	1.40	1.79	9.31	10.69	2.1	1.19	6.21	7.13	1.125	2.87	3.69			Same as above	Same as above
1337 A	7	16.6	0.9510	0.9156	0.9148	−36.2	.8	1.40	1.27	6.62	7.60	2.1	0.85	4.41	5.07	1.625	2.41	3.09			Heavy rust-colored scale on all surfaces	Rough pickled appearance over all surfaces
1338 A	10	28.9	0.9575	0.8661	0.8642	−93.3	1.9	1.40	3.27	17.06	19.60	2.1	2.18	11.37	13.07	2.375	1.87	2.40			Rust-colored film on all surfaces; definite indications of attack	Heavily pickled attack in exposed areas; clamped edges were protected
1339 A	13	39.4	0.9373	0.7398	0.7376	−199.7	2.2	1.40	7.01	36.52	41.95	2.1	4.67	24.35	27.97	3.125	1.43	1.84			Thin rust-colored film on all surfaces; heavy attack of exposed surfaces	Very heavily pickled attack in exposed areas; clamped edges stand out in relief
1340 A	18	19.9	0.9644	0.9576	0.9564	−8.0	1.2	1.40	0.28	1.46	1.68	2.1	0.19	0.97	1.12	4.375	0.94	1.21			Spotty rust-colored film on all surfaces	Very thin film on all surfaces; machine marks clearly visible
1341 A	21	13.1	0.9545	0.9550	0.9505	−4.0	12.0 4.5	1.40	9.80	0.14	0.76	0.87	2.1	0.09	0.51	0.58	5.125	0.72	0.92		Heavy rust-colored scale on all surfaces	Same as above
1342 A	24	9.7	0.9558	0.9644	0.9516	−4.2	13.4	1.57	0.13	0.68	0.78	2.1	0.09	0.51	0.58	5.875	0.56	0.72			Heavy dark film with flaky rust-colored scale on all surfaces	Same as above
							25.8	(11.37)														
B. 8 Zircaloy-2 Coupons																						
Z 11	2	9.9	0.7622	0.7478	0.7474	−14.8	.4	1.40	0.64	3.34	3.83	2.1	0.43	2.23	2.55	0.375	3.70	4.75			Dark film on all surfaces; rough etched appearance	All surfaces have a rough pickled appearance; some film retained along clamped edges
Z 17	3	10.8	0.7595	0.7456	0.7453	−14.2	.3	1.40	0.61	3.19	3.66	2.1	0.41	2.13	2.44	0.625	3.40	4.37			Same as above	Same as above
Z 18	8	19.4	0.7623	0.7505	0.7506	−11.2	.1	1.40	0.50	2.62	3.00	2.1	0.33	1.75	2.00	1.875	2.21	2.84			Heavy dark scale on all surfaces	All surfaces have rough pickled appearance; thin dark film retained in spots
Z 22	11	33.9	0.7450	0.7346	0.7343	−10.7	.3	1.40	0.46	2.40	2.75	2.1	0.31	1.60	1.83	2.625	1.70	2.18			Dark film on all surfaces; mild etched appearance	All surfaces have rough pickled appearance; thin dark film retained
Z 23	14	43.6	0.7497	0.7414	0.7408	−8.9	.6	1.40	0.39	2.03	2.33	2.1	0.26	1.35	1.55	3.375	1.31	1.68			Heavy dark scale on all surfaces	Thin dark film on all surfaces; the surfaces have a rough pickled appearance
Z 28	15	39.5	0.7534	0.7454	0.7453	−8.1	.1	1.40	0.35	1.83	2.11	2.1	0.23	1.22	1.41	3.625	1.21	1.55			Same as above	Same as above
Z 30	20	14.7	0.7666	0.7606	0.7598	−6.8	.8	1.40	0.30	1.56	1.79	2.1	0.20	1.04	1.19	4.875	0.79	1.01			Heavy dark film with spots of rust-colored scale on all surfaces	Same as above
Z 32	23	10.6	0.7663	0.7611	0.7604	−5.9	.7	1.40	0.25	1.32	1.52	2.1	0.17	0.88	1.01	5.625	0.61	0.78			Rough dark film on all surfaces	Thin dark film on all surfaces; the surfaces have a light pickled appearance
							3.2	9.80														
C. 8 Titanium 55AX Coupons																						
T 31	1	9.2	0.5256	0.5243	0.5231	−2.5	1.2	1.57	0.14	0.73	0.83	2.1	0.10	0.55	0.62	0.125	4.00	5.14			Thin oxide film on all surfaces; mild etched appearance and machine marks visible	Very thin film on all surfaces; machine marks clearly visible
T 32	6	14.6	0.5389	0.5378	0.5374	−1.5	.4	1.40	0.08	0.43	0.50	2.1	0.05	0.29	0.33	1.375	2.61	3.35			Dark film on all surfaces; machine marks visible	Same as above
T 33	9	23.0	0.5447	0.5436	0.5431	−1.5	.5	1.40	0.08	0.43	0.50	2.1	0.05	0.29	0.33	2.125	2.02	2.59			Heavy dark scale on all surfaces	Same as above
T 34	12	36.3	0.5391	0.5380	0.5380	−1.1	0	1.40	0.07	0.35	0.41	2.1	0.05	0.23	0.27	2.875	1.58	2.03			Dark film on all surfaces with heavy scale in spots	Same as above
T 35	16	29.4	0.5334	0.5324	0.5324	−1.0	0	1.40	0.06	0.32	0.37	2.1	0.04	0.21	0.25	3.875	1.11	1.43			Rust-colored film on all surfaces; possibly machine marks visible	Same as above
T 36	17	23.7	0.5396	0.5391	0.5380	−1.6	1.1	1.40	0.09	0.51	0.59	2.1	0.06	0.34	0.39	4.125	1.01	1.30			Same as above	Same as above
T 37	19	16.9	0.5429	0.5438	0.5416	−1.3	2.2	1.40	0.08	0.42	0.49	2.1	0.05	0.28	0.33	4.625	0.96	1.23			Rust-colored film on all surfaces	Same as above
T 39	22	11.7	0.5405	0.5454	0.5398	−0.7	5.6	1.40	0.04	0.22	0.26	2.1	0.03	0.15	0.17	5.375	0.66	0.85			Heavy rust-colored scale on all surfaces	Same as above

*Two corrosion rates are presented: one based on the total operation time of 1676 hr and the other based on the total radiation time of 1459 hr (3 Mwhr of reactor time equivalent to 1 hr of total radiation time).

11.0 11.37

TABLE 10. DATA FOR CORROSION SPECIMENS (continued)

Sample No.	Position	Average Flow Velocity Across Specimen (fps)	Weight Data: Initial (g)	As Removed (g)	Defilmed (g)	Change (mg)	Exposed Sample Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Exposed Area) (mpy): 1676 hr	1459 hr	Total Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Total Area) (mpy): 1676 hr	1459 hr	Distance from Front of First Specimen to Center of Specimen (in.)	Neutron Flux at Specimen Locations at 3 Mw (neutrons/cm^2/sec × 10^{-12})	Power Density at Specimen Locations at 3 Mw (w/ml)	Strain (μin./in.)	Stress (psi)	Appearance: As Removed	Appearance: Defilmed
II. 12 CORE STRESS SPECIMENS																					
A. 4 Type 17-4 PH Stainless Steel Specimens (17-4 PH Holders)																					
4P-7			8.7134	8.6915	8.6584	−55.0	33.1 19.5	0.14	0.75	0.86	20.0	0.14	0.73	0.83	2.813	1.70	2.18	2750	79,800	Heavy rust-colored scale on all surfaces; machine marks apparent	Thin dark stain over all surfaces; machine marks visible
4P-8			8.0237	7.9978	7.9896	−34.1	8.2 19.5	0.09	0.46	0.53	20.0	0.09	0.45	0.52	2.813	1.70	2.18	3370	97,700	Same as above	Same as above
SS-10	Holders		11.1303	10.9808	10.9770	−153.3	3.8 10.0	0.77	4.03	4.63	10.0	0.77	4.03	4.63	0.750	3.24	4.16			Same as above	Thin dark film retained; surface has pickled appearance
SS-12	Holders		11.1200	11.1304	11.1167	−3.3	13.7 10.0	0.02	0.09	0.10	10.0	0.02	0.09	0.10	4.750	0.82	1.05			Same as above	Thin dark film retained; machine marks clearly visible
4P-9			9.1264	9.1072	9.0973	−29.1	9.9 19.5	0.08	0.39	0.45	20.0	0.07	0.38	0.44	2.813	1.70	2.18	2750	79,800	Heavy rust-colored scale on all surfaces; scale has dimpled appearance	Thin dark film over all surfaces; machine marks visible
4P-10			8.7044	8.6695	8.6801	−24.3	11.6 19.5	0.06	0.33	0.38	20.0	0.06	0.32	0.37	2.813	1.70	2.18	3040	88,200	Heavy rust-colored scale on all surfaces; machine marks apparent	Same as above
SS-14	Holders		11.2178	11.1269	11.1216	−96.2	5.3 10.0	0.49	2.53	2.91	10.0	0.49	2.53	2.91	0.750	3.24	4.16			Same as above	Thin dark stain on all surfaces; surface has a rough pickled appearance
SS-15	Holders		11.1811	11.1932	11.1790	−2.1	14.2 10.0	0.01	0.06	0.07	10.0	0.01	0.06	0.07	4.750	0.82	1.05			Same as above	Thin dark stain on all surfaces; some film retained; surface has a pickled appearance
							8 8.3 97.5														
B. 4 Zircaloy-2 Specimens (Zircaloy-2 Holders)																					
Z 11			8.2206	8.1020	8.1001	−120.5	1.9 19.5	0.37	1.95	2.24	20.0	0.37	1.90	2.18	2.813	1.70	2.18	1680	23,500	Thin dark film over rough sandblasted surface	Iridescent film over relatively smooth sandblasted surface
Z 12			7.3280	7.2014	7.1982	−129.8	3.2 19.5	0.40	2.10	2.41	20.0	0.39	2.05	2.35	2.813	1.70	2.18	2020	28,300	Same as above	Iridescent film over relatively smooth sandblasted surface; possibly some attack along one compression edge
Z 7	Holders		9.2321				10.0				10.0				0.750	3.24	4.16			Thin dark film over all surfaces; screw broke off in holder	
Z 8	Holders		8.8615				10.0				10.0				4.750	0.82	1.05			Same as above	
Z 19			7.8472	7.7374	7.7364	−110.8	1.0 19.5	0.34	1.79	2.06	20.0	0.34	1.75	2.01	2.813	1.70	2.18	1860	26,000	Dark film over rough sandblasted surface	Thin iridescent film over relatively smooth sandblasted surface
Z 20			6.9463	6.8289	6.8272	−119.1	1.7 19.5	0.37	1.93	2.22	20.0	0.36	1.88	2.16	2.813	1.70	2.18	2040	28,600	Thin dark film over rough sandblasted surface	Same as above
							7.8 78.0														
Z 15	Holders		9.1262				10.0				10.0				0.750	3.24	4.16			Thin dark film over all surfaces; screw broke off in holder	
Z 16	Holders		9.2785				10.0				10.0				4.750	0.82	1.05			Same as above	
C. 4 Titanium (Ti-C-130-AM) Specimens (Titanium Holders)																					
Ti 3-9	Holders		5.7649	5.7527	5.7520	−12.9	.7 19.5	0.06	0.30	0.34	20.0	0.06	0.29	0.34	2.813	1.70	2.18	4640	74,200	Rust-colored film on all surfaces, disturbed at fulcrum and clamped end	Very, very thin film on all surfaces; machine marks clearly visible
Ti 3-10	Holders		5.5045	5.4928	5.4914	−13.1	1.4 19.5	0.06	0.30	0.35	20.0	0.06	0.30	0.34	2.813	1.70	2.18	5380	86,100	Same as above	Very, very thin film on all surfaces; machine marks clearly visible; specimen bowed
Ti 15	Holders		6.1451	6.1378	6.1361	−9.0	1.7 10.0	0.08	0.41	0.47	10.0	0.08	0.41	0.47	0.750	3.24	4.16			Rust-colored scale on all surfaces	Very, very thin film on all surfaces; machine marks clearly visible
Ti 17	Holders		6.2655	6.2698	6.2628	−2.7	7.0 10.0	0.02	0.12	0.14	10.0	0.02	0.12	0.14	4.750	0.82	1.05			Same as above	Same as above
Ti 3-7			5.4538	5.4425	5.4418	−12.0	.7 19.5	0.05	0.28	0.32	20.0	0.05	0.27	0.31	2.813	1.70	2.18	3450	55,200	Rust-colored film on all surfaces	Very, very thin film on all surfaces; machine marks visible; some attack adjacent to fulcrum contact

*Two corrosion rates are presented: one based on the total operation time of 1676 hr and the other based on the total radiation time of 1459 hr (3 Mwhr of reactor time equivalent to 1 hr of total radiation time).

11.5 72.5

TABLE 10. DATA FOR CORROSION SPECIMENS (continued)

Sample No.	Position	Average Flow Velocity Across Specimen (fps)	Weight Data: Initial (g)	As Removed (g)	Defilmed (g)	Change (mg)	Exposed Sample Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Exposed Area) (mpy): 1676 hr	1459 hr	Total Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Total Area) (mpy): 1676 hr	1459 hr	Distance from Front of First Specimen to Center of Specimen (in.)	Neutron Flux at Specimen Locations at 3 Mw (neutrons/cm^2/sec × 10^{-12})	Power Density at Specimen Locations at 3 Mw (w/ml)	Strain (μin./in.)	Stress (psi)	Appearance: As Removed	Appearance: Defilmed
C. 4 Titanium (Ti-C-130-AM) Specimens (Titanium Holders) (continued) 81.2 781.2																					
Ti 3-8			5.6881	5.6765	5.6746	−13.5	1.9 19.5	0.06	0.31	0.36	20.0	0.06	0.30	0.35	2.813	1.70	2.18	5750	92,000	Rust-colored film on all surfaces	Very, very thin film on all surfaces; machine marks visible; some attack adjacent to fulcrum contact
Ti 9	Holders		6.1129	6.1072	6.1047	−8.2	2.5 10.0	0.07	0.37	0.43	10.0	0.07	0.37	0.43	0.750	3.24	4.16			Rust-colored scale on all surfaces	Very, very thin film on all surfaces; machine marks clearly visible
Ti 10	Holders		6.1313	6.1427	6.1299	−1.4	12.8 10.0	0.01	0.06	0.07	10.0	0.01	0.06	0.07	4.750	0.82	1.05			Same as above	Very, very thin film on all surfaces; machine marks clearly visible; some spots of scale retained
							28.7 (118)														
III. 2 CORE SLEEVE SPECIMEN ASSEMBLIES (16 SPECIMENS)																					
A. Type 309 SCb Stainless Steel Rod and 8 Type 309 SCb Sleeves																					
9C-1	1		0.9720	0.9265	0.9237	−48.3	2.8 4.84	0.50	2.61	2.99	4.84	0.50	2.61	2.99	3.50	3.05	3.92			End slightly damaged during removal; dark-brown scale on all surfaces	Machining marks still visible in lightly pitted surface; same film retained
9C-2	2		0.9938	0.9561	0.9454	−48.4	10.7 4.84	0.50	2.61	2.99	4.84	0.50	2.61	2.99	2.98	2.57	3.30			One end heavily damaged during removal; dark-brown scale on all surfaces	Same as above
9C-3	3		0.9906	0.9663	0.9610	−29.6	5.3 4.84	0.31	1.62	1.86	4.84	0.31	1.62	1.86	2.58	2.17	2.79			End slightly damaged during removal; dark-brown scale on all surfaces	Same as above
9C-4	4		0.9968	0.9818	0.9777	−19.1	4.1 4.84	0.20	1.04	1.20	4.84	0.20	1.04	1.20	2.19	1.81	2.32			Same as above	Machining marks still visible in lightly etched surface
9C-5	5		0.9831	0.9710	0.9667	−16.4	4.3 4.84	0.17	0.89	1.02	4.84	0.17	0.89	1.02	1.88	1.52	1.95			Slightly etched appearance; dark-brown scale on all surfaces	Spiral machine marks clearly visible; some film retained
9C-6	6		0.9880	0.9800	0.9755	−12.5	4.5 4.84	0.13	0.68	0.78	4.84	0.13	0.68	0.78	1.61	1.28	1.64			Machine marks apparently visible; dark-brown scale on all surfaces	Spiral machine marks clearly visible; surface clean
9C-7	7		0.9928	0.9941	0.9792	−13.6	14.9 4.84	0.14	0.73	0.84	4.84	0.14	0.73	0.84	1.38	1.08	1.39			Spotty dark-brown scale on all surfaces	Spiral machine marks clearly visible; some film retained
9C-8	8		0.9940	0.9918	0.9812	−12.8	10.6 4.84	0.13	0.68	0.78	4.84	0.13	0.68	0.78	1.29	0.91	1.17			Heavy dark-brown scale on all surfaces	Same as above
	Rod		16.9905	16.9350			— 19.38				19.38									Rod broken during the removal of the specimens; surface mechanically scarred	
B. Type 347 Stainless Steel Rod and 8 Type 347 Sleeves 57.2 38.72																					
S-23	1		0.8847	0.7595	0.7574	−127.3	2.1 4.84	1.29	6.72	7.72	4.84	1.29	6.72	7.72	3.50	3.05	3.92			Very heavy dark-brown scale on all surfaces	Some scale retained; surfaces have longitudinal grooves similar to the bark of a hickory tree
S-24	2		0.9235	0.8750	0.8716	−51.9	3.4 4.84	0.53	2.76	3.17	4.84	0.53	2.76	3.17	2.98	2.57	3.30			Same as above	Same as above
S-25	3		0.9121	0.8871	0.8829	−29.2	4.2 4.84	0.30	1.56	1.80	4.84	0.30	1.56	1.80	2.58	2.17	2.79			Same as above	Surface has a pickled appearance retaining some film; grooves similar to the bark of a hickory tree
S-26	4		0.9157	0.9010	0.8958	−19.9	5.2 4.84	0.20	1.04	1.20	4.84	0.20	1.04	1.20	2.19	1.81	2.32			Same as above	Same as above
S-27	5		0.9047	0.8982	0.8932	−11.5	5.0 4.84	0.12	0.63	0.72	4.84	0.12	0.63	0.72	1.88	1.52	1.95			Same as above	Same as above
S-28	6		0.9072	0.9041	0.8986	−8.6	5.5 4.84	0.09	0.47	0.54	4.84	0.09	0.47	0.54	1.61	1.28	1.64			Same as above	Surface has a pickled appearance; clean
S-29	7		0.9205	0.9215	0.9145	−6.0	7.0 4.84	0.06	0.31	0.36	4.84	0.06	0.31	0.36	1.38	1.08	1.39			Same as above	Surface has a pickled appearance; retaining same film
S-30	8		0.9185	0.9251	0.9164	−2.1	8.7 4.84	0.02	0.10	0.12	4.84	0.02	0.10	0.12	1.29	0.91	1.17			Same as above	Surface has a pickled appearance, retaining some film; machine marks barely visible
	Rod		17.4491	17.3690	17.3375	−111.6	30.5 9.38	0.28	1.46	1.68	19.38	0.28	1.46	1.68							

*Two corrosion rates are presented: one based on the total operation time of 1676 hr and the other based on the total radiation time of 1459 hr (3 Mwhr of reactor time equivalent to 1 hr of total radiation time).

70.6 33.88 / 53.26

TABLE 10. DATA FOR CORROSION SPECIMENS (continued)

Sample No.	Position	Average Flow Velocity Across Specimen (fps)	Weight Data: Initial (g)	Weight Data: As Removed (g)	Weight Data: Defilmed (g)	Change (mg)	Exposed Sample Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Exposed Area) (mpy) 1676 hr	Corrosion Rate* (Exposed Area) (mpy) 1459 hr	Total Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Total Area) (mpy) 1676 hr	Corrosion Rate* (Total Area) (mpy) 1459 hr	Distance from Front of First Specimen to Center of Specimen (in.)	Neutron Flux at Specimen Locations at 3 Mw (neutrons/cm^2/sec × 10^{-12})	Power Density at Specimen Locations at 3 Mw (w/ml)	Strain (μin./in.)	Stress (psi)	Appearance: As Removed	Appearance: Defilmed
IV. 24 IN-LINE SAMPLE COUPONS																					
A. 8 Type 347 Stainless Steel Coupons																					
836 A	4	11.4	0.9520	0.9608	0.9416	−10.4	19.2 1.40	0.36	1.88	2.16	2.1	0.24	1.25	1.44	0.875					Heavy rustlike scale over all surfaces, flaked in spots	Clean surfaces; machine marks visible
837 A	5	12.6	0.9521	0.9645	0.9462	−5.9	18.3 1.40	0.21	1.09	1.26	2.1	0.14	0.73	0.84	1.125					Same as above	Very clean; clear-cut machine marks
838 A	7	15.7	0.9580	0.9712	0.9574	−0.6	13.8 1.40	0.02	0.10	0.12	2.1	0.01	0.05	0.06	1.625					Same as above	Very thin film on surface; machine marks clearly visible
839 A	10	25.1	0.9748	0.9854	0.9596	−15.2	25.8 1.40	0.53	2.76	3.17	2.1	0.35	1.82	2.10	2.375					Same as above	Very thin film retained on lightly etched surfaces; some machine marks visible
840 A	13	37.8	0.9497	0.9578	0.9489	−0.8	8.9 1.40	0.03	0.16	0.18	2.1	0.02	0.10	0.12	3.125					Same as above	A few small spots of black scale; machine marks visible
841 A	18	21.5	0.9620	0.9680	0.9606	−1.4	7.4 1.40	0.05	0.26	0.30	2.1	0.03	0.16	0.18	4.375					Same as above	Very thin brown film on all surfaces; machine marks visible
842 A	21	13.9	0.9536	0.9573	0.9372	−16.4	20.1 1.40	0.58	3.02	3.47	2.1	0.39	2.03	2.34	5.125					Same as above	Same brown scale in spots; slight electrode effect
843 A	24	10.0	0.9404	0.9486	0.9336	−6.8	15.0 1.57	0.21	1.09	1.26	2.1	0.16	0.83	0.96	5.875					Same as above	Some very small spots of scale retained; machine marks visible
							128.5 11.37														
B. 8 Zircaloy-2 Coupons																					
Z 0	2	9.5	0.7449	0.7574	0.7449	0.0	12.5 1.40	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.375					Same as above	Thin dark film retained on all surfaces
Z 2	3	10.3	0.7698	0.7850	0.7699	+0.1	15.1 1.40				2.1				0.625					Same as above	Same as above
Z 4	8	17.9	0.7726	0.7850	0.7727	+0.1	12.3 1.40				2.1				1.875					Same as above	Same as above
Z 6	11	32.8	0.7431	0.7526	0.7734	+0.3	14.8 1.40				2.1				2.625					Same as above	Same as above
Z 7	14	41.0	0.7660	0.7750	0.7768	+0.8	6.8 1.40				2.1				3.375					Same as above	Same as above
Z 8	15	46.1	0.7597	0.7678	0.7609	+1.2	6.9 1.40				2.1				3.625					Same as above	Same as above
Z 9	20	15.5	0.7481	0.7575	0.7483	+0.2	9.2 1.40				2.1				4.875					Same as above	Same as above
Z 10	23	11.1	0.7697	0.7812	0.7699	+0.2	11.3 1.40				2.1				5.625					Same as above	Same as above
C. 8 Titanium 55AX Coupons							67.3 840														
T 17	1	8.9	0.5376	0.5471	0.5368	−0.8	109 1.57	0.04	0.21	0.24	2.1	0.03	0.16	0.18	0.125					Same as above	Clean surfaces; machine marks clearly visible
T 19	6	13.9	0.5442	0.5574	0.5439	−0.3	13.5 1.40	0.02	0.10	0.12	2.1	0.01	0.05	0.06	1.375					Same as above	Clean; machine marks visible
T 20	9	20.9	0.5288	0.5412	0.5276	−1.2	13.6 1.40	0.07	0.36	0.42	2.1	0.05	0.26	0.30	2.125					Same as above	Clean surfaces; machine marks visible
T 21	12	34.9	0.5374	0.5477	0.5360	−1.4	11.7 1.40	0.09	0.47	0.54	2.1	0.06	0.31	0.36	2.875					Same as above	Same as above
T 22	16	32.9	0.5335	0.5400	0.5335	0.0	6.5 1.40	0.00	0.00	0.00	2.1	0.00	0.00	0.00	3.875					Same as above	Very clean surfaces; machine marks visible
T 23	17	25.9	0.5386	0.5449	0.5386	0.0	6.3 1.40	0.00	0.00	0.00	2.1	0.00	0.00	0.00	4.125					Same as above	Same as above
T 24	19	18.2	0.5281	0.5348	0.5274	−0.7	7.4 1.40	0.04	0.21	0.24	2.1	0.03	0.16	0.18	4.625					Same as above	Clean surfaces; machine marks visible
T 30	22	12.1	0.5242	0.5331	0.5240	−0.2	9.1 1.40	0.01	0.05	0.06	2.1	0.01	0.05	0.06	5.375					Same as above	Same as above
							68.1 11.37														
V. SPECIAL IN-LINE STRESS SPECIMENS																					
A. 2 Type 17-4 PH Stainless Steel Specimens (17-4 PH Holders)																					
4P-5 } B			7.9003	7.9738	7.8871	−13.2	86.7 9.5	0.034	0.18	0.20	20.0	0.033	0.17	0.20				3060	88,700	Rust-colored scale on all surfaces, except along fulcrum center line	Thin dark stain over all surfaces; spot of arc burn from defilming; machine marks visible
4P-6 } B			8.5218	8.5882	8.5189	−2.9	69.3 9.5	0.008	0.04	0.05	20.0	0.008	0.04	0.05				2590	75,100	Same as above	Thin dark stain over all surfaces; machine marks visible

*Two corrosion rates are presented: one based on the total operation time of 1676 hr and the other based on the total radiation time of 1459 hr (3 Mwhr of reactor time equivalent to 1 hr of total radiation time).

TABLE 10. DATA FOR CORROSION SPECIMENS (continued)

Sample No.	Position	Average Flow Velocity Across Specimen (fps)	Weight Data: Initial (g)	Weight Data: As Removed (g)	Weight Data: Defilmed (g)	Change (mg)	Exposed Sample Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Exposed Area) (mpy): 1676 hr	Corrosion Rate* (Exposed Area) (mpy): 1459 hr	Total Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Total Area) (mpy): 1676 hr	Corrosion Rate* (Total Area) (mpy): 1459 hr	Distance from Front of First Specimen to Center of Specimen (in.)	Neutron Flux at Specimen Locations at 3 Mw (neutrons/cm^2/sec × 10^{-12})	Power Density at Specimen Locations at 3 Mw (w/ml)	Strain (μin./in.)	Stress (psi)	Appearance: As Removed	Appearance: Defilmed
A. 2 Type 17-4 PH Stainless Steel Specimens (17-4 PH Holders) (continued)																					
SS-13	Holders		10.9784	11.0114	10.9775	−0.9	32.9	10.0	0.005	0.03	0.03	10.0	0.005	0.03	0.03					Rust-colored scale on all surfaces	Thin dark stain over all surfaces; machine marks visible
SS-16	Holders		11.1961	11.2304	11.1964	+0.3	34.0	10.0				10.0								Same as above	Thin dark stain over all surfaces; machine marks visible; some spots of film retained
							222.9	59.0													
B. 2 Zircaloy-2 Stress Specimens (Zircaloy-2 Holders)																					
Z-13	C		8.4754	8.5710	8.5160	+40.6	55.9	19.5				20.0						1750	24,500	Heavy rust-colored scale on all surfaces; flaked in spots	Heavy rust-colored to dark over all surfaces
Z-14	C		7.4866	7.5699	7.5378	+51.2	31.1	19.5				20.0						2070	29,000	Same as above	Same as above
Z-9	Holders		9.2885	9.3318	9.3276	+39.1	4.2	10.0				10.0								Same as above	Same as above
Z-10	Holders		8.9017	8.9427	8.9334	+31.7	9.3	10.0				10.0								Rough rust-colored scale on all surfaces	Same as above
							99.6	59.0													
C. 2 Titanium Ti-C-130-AM Stress Specimens (Ti-C-130-AM Holders)																					
Ti 3-3	A		5.4528	5.5252	5.4493	−3.5	75.9	19.5	0.016	0.08	0.10	20.0	0.016	0.08	0.10			5705	91,300	Rust-colored scale on all surfaces	Thin film on all surfaces; machine marks clearly visible; edges rough
Ti 3-4	A		5.3963	5.4625	5.3934	−2.9	69.1	19.5	0.013	0.07	0.08	20.0	0.013	0.07	0.08			4250	68,000	Same as above	Same as above
Ti-11	Holders		6.0750	6.1106	6.0755	+0.5	35.1	10.0				10.0								Same as above	Same as above
Ti-12	Holders		5.9764	6.0078	5.9771	+0.7	30.7	10.0				10.0								Same as above	Same as above
							210.8	59.0													
VI. ZIRCALOY-2 CORE COUPON HOLDER																					
A	No. 19		82.4080																		
B	No. 19		79.4500				~160					~160									
VII. ZIRCALOY-2 IN-LINE COUPON HOLDER																					
A	No. 20		93.8547																		
B	No. 20		93.7657				~160					~160									
VIII. 16 PRESSURIZER STRESS SPECIMENS																					
A. 4 Type 347 Stainless Steel Specimens (Type 347 Holders)																					
(1) Liquid Samples																					
SS-3	B		10.2075	10.3029	10.2047	−2.8	98.2	19.5	0.007	0.04	0.04	20.0	0.007	0.04	0.04			1010	29,300	Heavy, dark rust-colored scale over all surfaces	Very thin dark stain over all surfaces; machine marks visible
SS-5	B		10.0356	10.1230	10.0295	−6.1	93.5	19.5	0.015	0.08	0.09	20.0	0.015	0.08	0.09			1060	30,700	Same as above	Surfaces very clean; machine marks visible
SS-19	Holders		11.2008	11.2480	11.1935	−1.3	54.5	10.0	0.006	0.03	0.04	10.0	0.006	0.03	0.04					Same as above	Very thin dark stain; machine marks visible
SS-20	Holders		11.1100	11.1508	11.1116	+1.6	39.2	10.0				10.0								Same as above	Some spots of dark stain retained; machine marks visible in clean areas
							285.4	59.0													
(2) Vapor Samples																					
SS-1	A		9.9966	9.9949	9.9938	−2.8	1.1	19.5	0.007	0.04	0.04	20.0	0.007	0.04	0.04			1060	30,700	Heavy rust-colored scale over all surfaces	Very thin dark stain over all surfaces; machine marks visible
SS-2	A		10.3307	10.3312	10.3194	−11.3	11.8	19.5	0.028	0.15	0.17	20.0	0.027	0.14	0.16			995	28,900	Heavy, dark rust-colored scale over all surfaces	Same as above
SS-17	Holders		11.1088	11.1101	11.1098	+1.0	.3	10.0				10.0								Dark film over all surfaces; machine marks visible	Thin dark stain over all dark surfaces
SS-18	Holders		10.9746	10.9786	10.9753	+0.7	3.3	10.0				10.0								Same as above	Thin dark stain over all dark surfaces; machine marks visible
							16.5	59.0													

*Two corrosion rates are presented: one based on the total operation time of 1676 hr and the other based on the total radiation time of 1459 hr (3 Mwhr of reactor time equivalent to 1 hr of total radiation time).

TABLE 10. DATA FOR CORROSION SPECIMENS (continued)

Sample No.	Position	Average Flow Velocity Across Specimen (fps)	Weight Data: Initial (g)	Weight Data: As Removed (g)	Weight Data: Defilmed (g)	Change (mg)	Exposed Sample Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Exposed Area) (mpy): 1676 hr	Corrosion Rate* (Exposed Area) (mpy): 1459 hr	Total Area (cm^2)	Corrosion Penetration (mils)	Corrosion Rate* (Total Area) (mpy): 1676 hr	Corrosion Rate* (Total Area) (mpy): 1459 hr	Distance from Front of First Specimen to Center of Specimen (in.)	Neutron Flux at Specimen Locations at 3 Mw (neutrons/cm^2/sec × 10^{-12})	Power Density at Specimen Locations at 3 Mw (w/ml)	Strain (μin./in.)	Stress (psi)	Appearance: As Removed	Appearance: Defilmed
B. 4 Type 17-4 PH Stainless Steel Specimens (17-4 PH Holders)																					
(1) Liquid Samples																					
4P-3	H		8.4325	8.5239	8.3315	−101.0	192.4	19.5	0.262	1.37	1.57	20.0	0.255	1.33	1.53				3390	98,300	Heavy dark scale over all surfaces with spots of rust-colored scale	Some dark film retained; remainder of surface very bright
4P-4			9.0298	9.1312	9.0080	−21.8	123.2	19.5	0.057	0.30	0.34	20.0	0.056	0.29	0.34				2750	79,700	Same as above	Some dark film on one end; machine marks visible; one side has a lightly etched appearance
SS-9	Holders		11.1805	11.2382	11.1751	−5.4	63.1	10.0	0.027	0.14	0.16	10.0	0.027	0.14	0.16						Same as above	Thin dark stain over all surfaces; machine marks clearly visible
SS-11			11.2635	11.3286	11.2629	−0.6	55.7	10.0	0.003	0.02	0.02	10.0	0.003	0.02	0.02						Same as above	Same as above
							437.4	59.0													
(2) Vapor Samples																					
4P-1	G		8.2506	8.2485	8.2216	−29.0	26.9	19.5	0.075	0.39	0.45	20.0	0.073	0.38	0.44				2820	81,800	Thin dark film over all surfaces	Thin dark stain with some film retained; machine marks visible
4P-2			8.1314	8.1315	8.0907	−40.7	40.8	19.5	0.105	0.55	0.63	20.0	0.102	0.53	0.61				2810	81,500	Same as above	Thin dark stain with some scale retained on one end
SS-7	Holders		11.2133	11.2285	11.2067	−6.6	21.8	10.0	0.033	0.17	0.20	10.0	0.033	0.17	0.20						Heavy dark film over all surfaces; machine marks apparent in spots	Thin dark stain over all surfaces; machine marks clearly visible
SS-8			11.1578	11.1618	11.1570	−0.8	4.8	10.0	0.004	0.02	0.02	10.0	0.004	0.02	0.02						Same as above	Same as above
							94.3	59.0													
C. 4 Zircaloy-2 Specimens (Zircaloy-2 Holders)																					
(1) Liquid Samples																					
Z-15	D		7.7924	7.8812	7.8558	+63.4	254	19.5				20.0							1850	25,900	Heavy, granular dark-colored scale on all surfaces	Heavy dark film on all surfaces
Z-16			7.9547	8.0456	7.9930	+38.3	52.6	19.5				20.0							1870	26,200	Same as above	Heavy dark scale retained on all surfaces
Z-11	Holders		9.2596	9.2945	9.2791	+19.5	13.4	10.0				10.0									Same as above	Same as above
Z-12			9.3107	9.3587	9.3415	+30.8	17.2	10.0				10.0									Same as above	Same as above
							110.6	59													
(2) Vapor Samples																					
Z-17	E		7.5884	7.5901	7.5912	+2.8	−.9	19.5				20.0							1630	22,800	Thin dark film over granular surface	Thin dark scale retained on all surfaces
Z-18			7.4265	7.4301	7.4293	+2.8	.8	19.5				20.0							1880	26,300	Same as above	Same as above
Z-13	Holders		8.7486	8.7542	8.7516	+3.0	2.6	10.0				10.0									Heavy, flaky dark scale over all surfaces; machine marks visible	Thin dark film retained on all surfaces
Z-14			8.8211	8.8361	8.8338	+12.7	2.3	10.0				10.0									Same as above	Same as above
							5.7	39.5													
D. 4 Titanium (Ti-C-130-AM) Specimens (Ti-C-130-AM Holders)																					
(1) Liquid Samples																					
Ti 3-5	F		5.7622	5.8465	5.7592	−3.0	87.3	19.5	0.013	0.07	0.08	20.0	0.013	0.07	0.08				3270	52,300	Heavy rust-colored scale over all surfaces; flaking in spots	Thin iridescent film on one end; machine marks clearly visible
Ti 3-6			5.6530	5.7263	5.6504	−2.6	75.9	19.5	0.012	0.06	0.07	20.0	0.012	0.06	0.08				4500	72,000	Same as above	Same as above
Ti-14	Holders		6.1481	6.1958	6.1469	−1.2	48.9	10.0	0.010	0.05	0.06	10.0	0.010	0.05	0.06						Heavy rust-colored scale over all surfaces;	Some small spots of scale are retained; sharp edges are rough
Ti-16			6.1502	6.1987	6.1159	−34.3	82.8	10.0	0.297	1.55	1.78	10.0	0.297	1.55	1.78						Same as above	Very thin film over all surfaces; machine marks clearly visible
							294.9	59.0													
(2) Vapor Samples																					
Ti 3-1	**C		5.4427	5.4427	5.4394	−3.3	3.3	19.5	0.015	0.08	0.09	20.0	0.015	0.08	0.09				4480	71,700	Thin film with spots of scale over all surfaces; machine marks visible	Thin iridescent film on one end; machine marks clearly visible
Ti 3-2			5.7869	5.8178	5.7836	−3.3	34.2	19.5	0.015	0.08	0.09	20.0	0.015	0.08	0.09				5320	85,100	Thin film with spots of scale over all surfaces; scale streaked in areas below solution line; machine marks visible	Same as above
Ti-4	Holders		6.2111	6.2221	6.2088	−2.3	13.3	10.0	0.020	0.10	0.12	10.0	0.020	0.10	0.12						Thin film with spots of scale over all surfaces; machine marks visible	Very thin film retained; sharp edges are rough
Ti-5			6.0445	6.0547	6.0384	−6.1	16.3	10.0	0.053	0.28	0.32	10.0	0.053	0.28	0.32						Same as above	Same as above

*Two corrosion rates are presented: one based on the total operation time of 1676 hr and the other based on the total radiation time of 1459 hr (3 Mwhr of reactor time equivalent to 1 hr of total radiation time).

**Due to a large deflection this specimen was probably exposed to liquid.

67.1 59.0

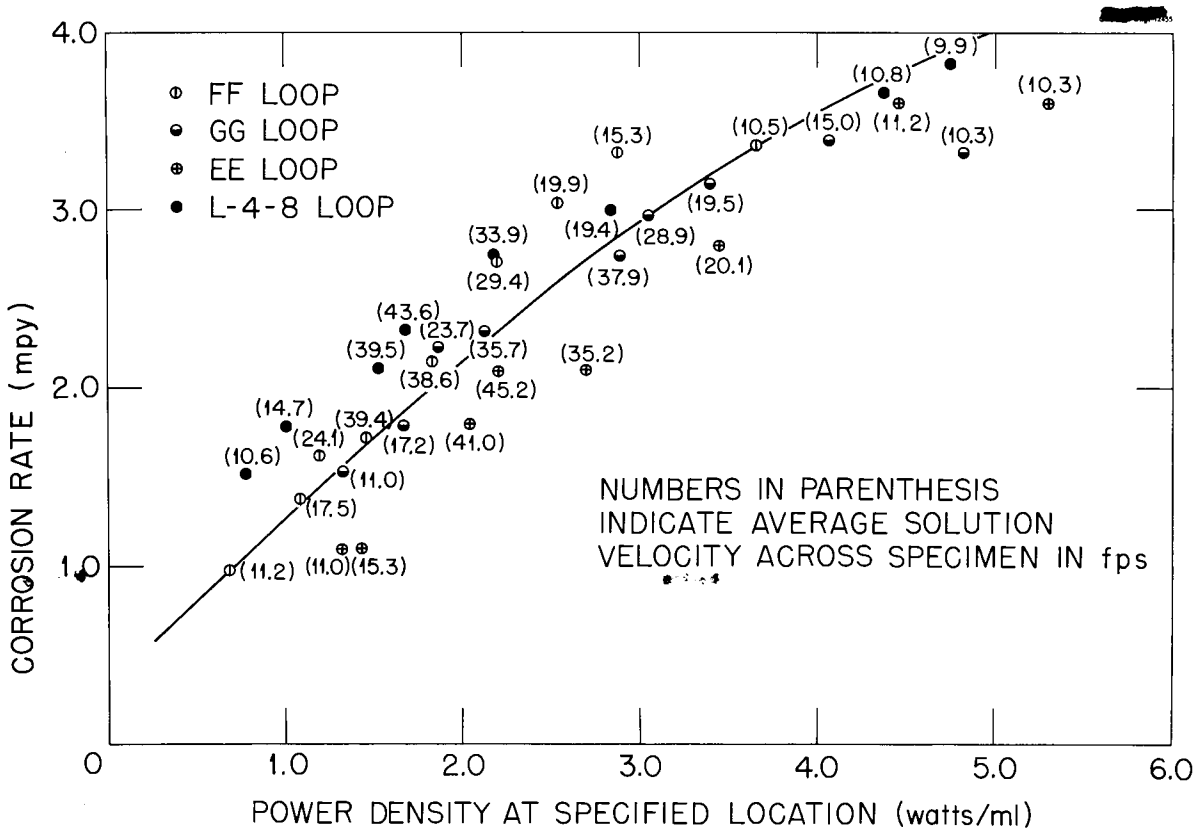

Fig. 11. Corrosion Rate of Zircaloy-2 Core Coupons vs Power Density at Specified Location. Corrosion rates calculated on exposed areas and radiation time.

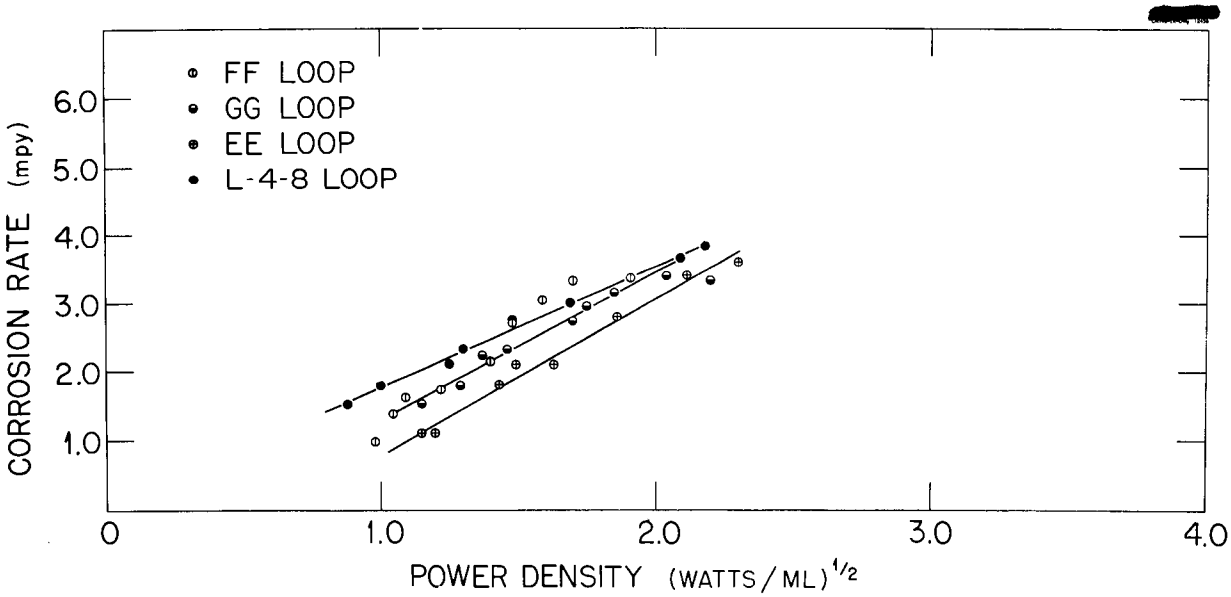

Fig. 12. Corrosion Rate of Zircaloy-2 Coupons vs the Square Root of Power Density. Corrosion rates calculated on exposed areas and radiation time.

TABLE 11. SOME MAJOR OPERATING VARIABLES FOR LOOPS CONTAINING Zr-2 CORE COUPONS

Loop	Circulation Time (hr)	LITR Energy (Mwhr)	Per Cent Operating Time with LITR at Power	Fission and Gamma Heat (w)	Initial Solution[a]			
					U (mg/ml)	Cu (*m*)	H_2SO_4 (*m*)	Cr (ppm)
FF	690	1400	67.6	877	40.0	0.031	0.04	
GG	1060	2700	84.9	1100	40.0	0.031	0.04	320
EE	630	1610	85.2	837	40.0	0.031	0.008[b]	
L-4-8	1676	4377	87.1	~925[c]	40.0	0.031	0.04	

[a]Solution removed from inventory during sampling replaced by solution of similar composition.

[b]Makeup solution contained 0.04 *m* H_2SO_4.

[c]Removal of ANP experiment during operation of this loop caused increase from 825 to 1000 w, which decreased to 970 w at termination of the experiment.

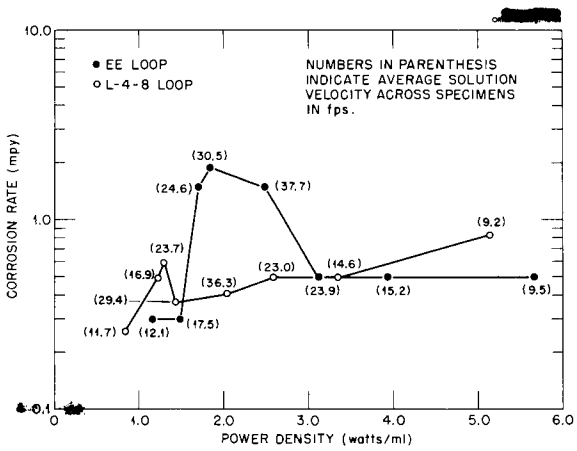

Fig. 13. Titanium 55AX Core Coupon Corrosion Rates vs Power Density at Coupon Position. Rates calculated from exposed areas and radiation time.

rate of these specimens of ±0.07 mpy. Hence the above rate values are considered to be significant.

Stainless Steel

Type 347 Core and In-Line Holder Coupons. – Corrosion-rate values for the type 347 core coupons are plotted in Fig. 14 in the manner described above for Zircaloy-2 and titanium. The results obtained in the two previous experiments which were equipped with similarly located specimens are plotted also. The pattern of corrosion among the core coupons from this loop is more complex than that observed for the identical array in experiment EE. The accelerating effect on corrosion of high radiation

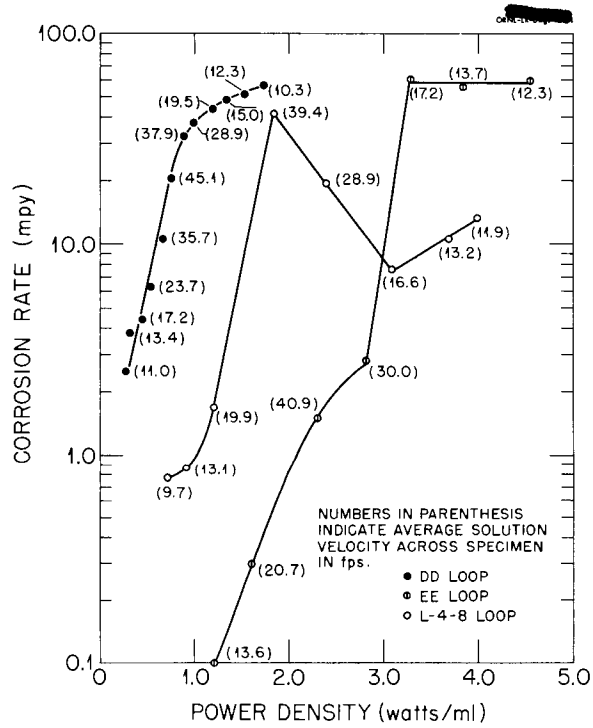

Fig. 14. Type 347 Stainless Steel Core Coupon Corrosion Rates vs Power Density at Coupon Position. Rates calculated from exposed areas and radiation time.

intensities was less pronounced than for the previous loop. However, in contrast with the previous results, the present results indicate a strong accelerating effect of velocity. In this experiment, the average corrosion rate determined for each of

the three specimens located nearest the front of the core and exposed to a maximum solution velocity of about 17 fps is about 10 mpy. However, the rates determined for the next two steel specimens in the array were 20 and 40 mpy, respectively. The average solution velocities past these specimens were about 29 fps and 39 fps, respectively. In the previous experiment, the corrosion rates determined for the first three specimens were, in each case, about 60 mpy. The rates for the remainder of the specimens were all below 3 mpy.

It can be tentatively postulated that the higher acidity of the solution employed in this experiment was responsible for both differences noted between the results of this and the previous loop. The reduction of the radiation-induced corrosion at low velocities is consistent with the results of in-pile bomb experiments,[5] and an increase in the velocity effect on corrosion by the addition of sulfuric acid to uranyl sulfate solutions is commonly observed in out-of-pile tests.

However, no velocity effect was observed for the in-line steel specimens in this loop. The average corrosion rate determined for the in-line coupons is 1.5 mpy. The highest rate found for a given specimen is 3.5 mpy, and the lowest is 0.1 mpy.

Types 347 and 309 SCb Core Sleeve Specimens. – As mentioned previously, it was apparent from visual inspection that most of the type 347 sleeves were marked with longitudinal grooves and were not uniformly attacked. The similarly located type 309 SCb sleeve specimens appeared to be more uniformly attacked. As shown graphically in Fig. 15, the results of weight measurements indicate that the degree of attack of these specimens increased with increasing power density.

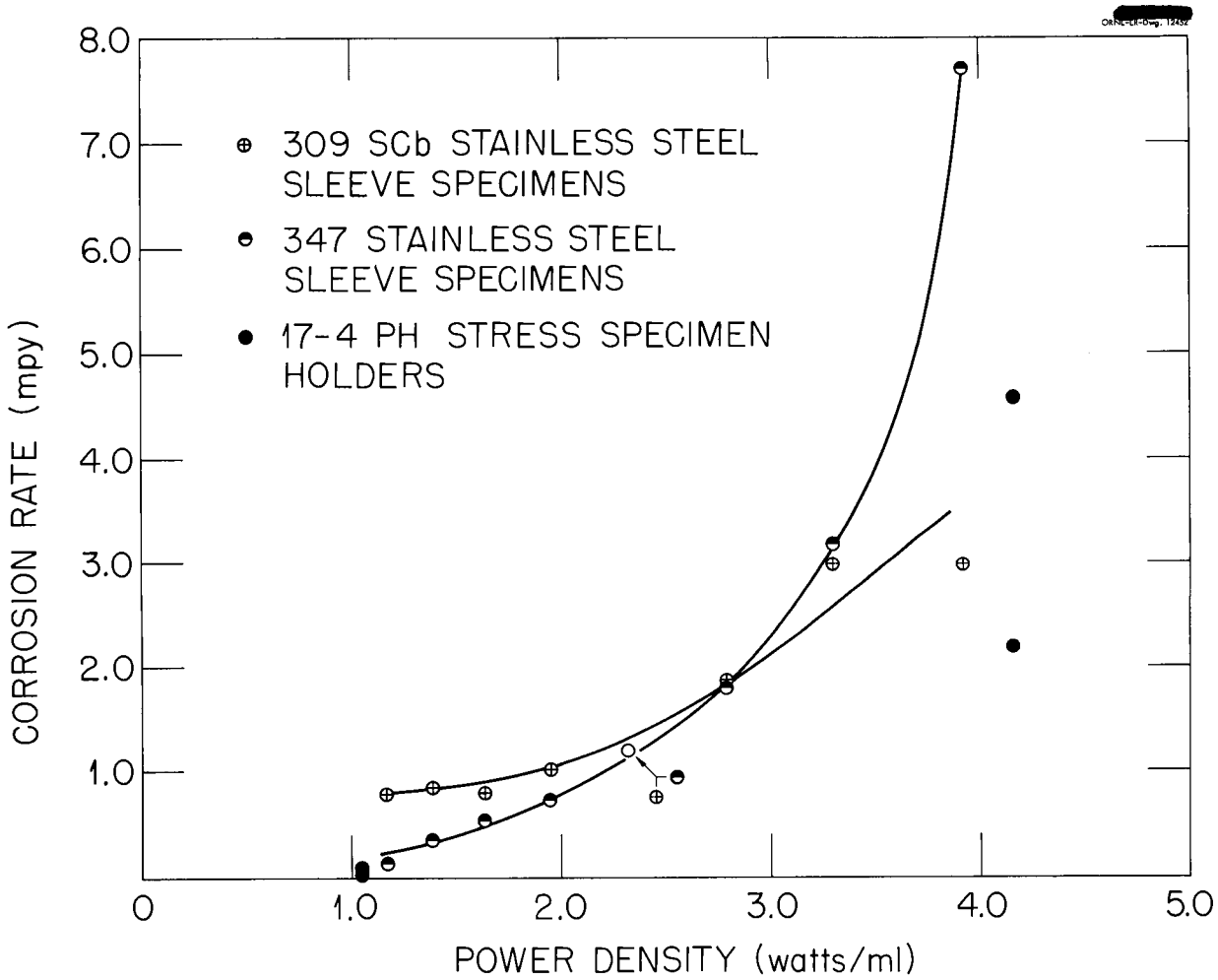

Fig. 15. Stainless Steel Core Sleeve-Specimen Corrosion Rates vs Power Density.

Corrosion-rate values determined for the type 17-4 PH stress-specimen holders in the core are also plotted in Fig. 15.

Stress Specimens

Microscopic examination of the various stress specimens revealed no surface evidence of any stress-corrosion cracking. In addition, there was no evidence from weight-loss determinations that the average corrosion rate of any of the different materials was adversely affected by the stress.

Metallographic examination of these specimens remains to be done.

Correlation Between Nickel and Weight Data

The total amount of steel oxidized during the loop operation according to nickel data was 19.5 g. From the specimen-weight data, it may be estimated, with certain assumptions as a basis, that the total amount of steel oxidized was 22.4 g. The basic assumptions are as follows: (1) all steel surfaces in contact with high-temperature solution, excluding the core, corroded uniformly and at an average rate equal to that for the in-line specimens, and (2) the attack of a steel surface which was at given flux in the core was the same as that measured for sleeve specimens which were located outside the core holder and in the same given flux. It was also assumed that the surface of the core cap corroded at the rate determined for the type 347 sleeve specimen which was in the highest flux. The near agreement of the values determined by these two methods suggests that these assumptions may be approximately correct.

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